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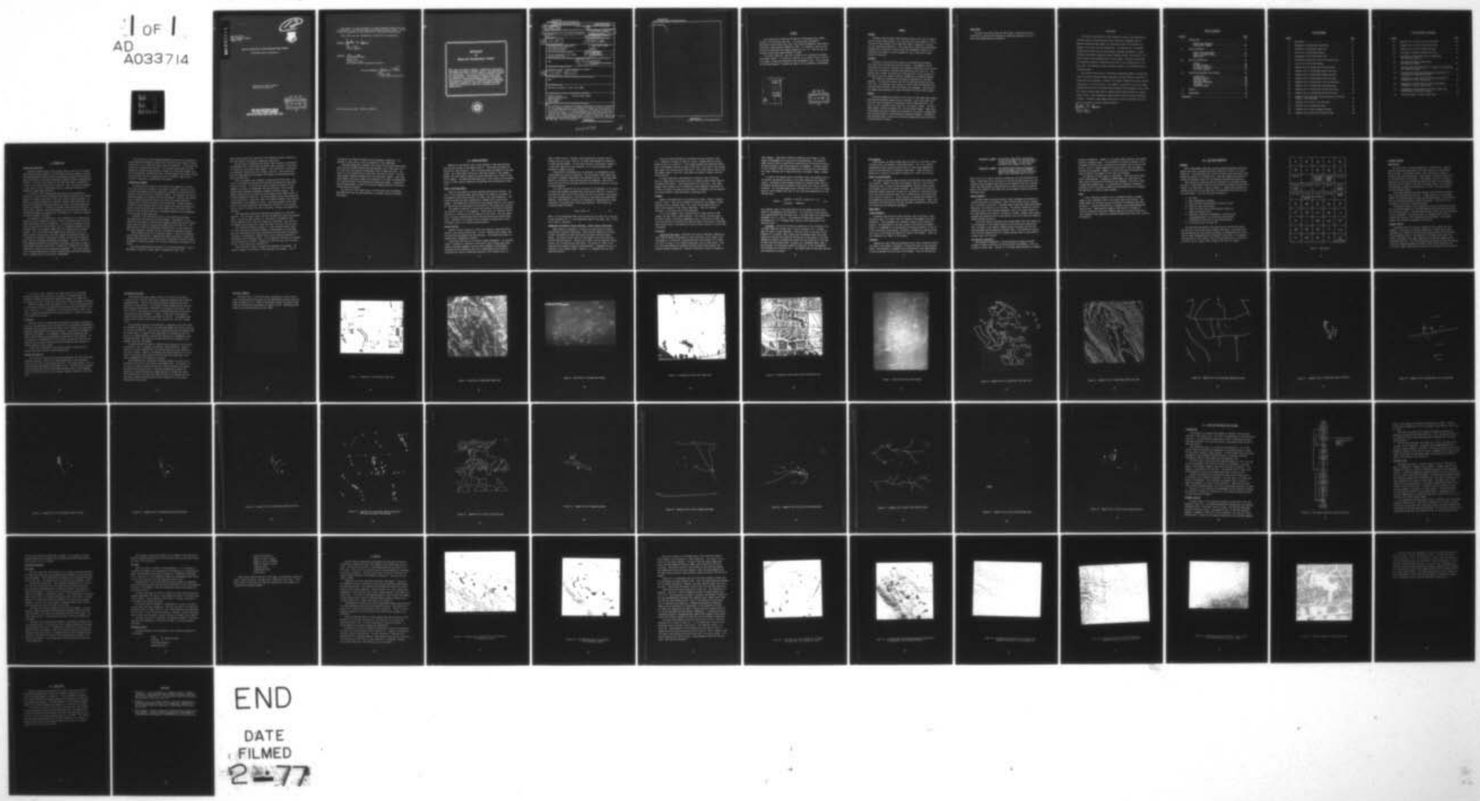

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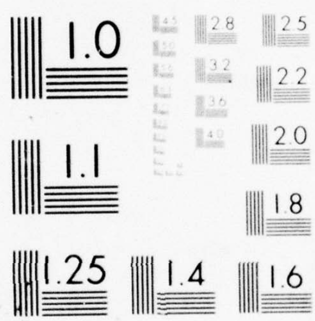

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RADC-TR-76-290
Final Technical Report
October 1976

DIGITAL SIMULATION OF HIGH RESOLUTION RADAR IMAGERY

Technology Service Corporation

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ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
GRIFFISS AIR FORCE BASE, NEW YORK 13441

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APPROVED: John N. Horn

JOHN N. HORN
Project Engineer

APPROVED: Howard Davis

HOWARD DAVIS
Technical Director
Intelligence and Reconnaissance Division

FOR THE COMMANDER: John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

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This study was an exploratory development program with the purpose of establishing the fundamental capability of simulating SAR imagery of future systems for use in exercising change detection processors. To this end the objectives of program were twofold: (1) to develop algorithms and techniques for simulating high resolution imagery for future SAR systems using aerial photography, topographical maps, and SAR imagery from present systems as source data, and (2) to generate a set of simulated imagery under a variety of conditions to demonstrate → next page

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PREFACE

This study was initiated by the Rome Air Development Center (RADC), Griffiss Air Force Base, New York. The research was conducted by Technology Service Corporation (TSC), 2811 Wilshire Boulevard, Santa Monica, California, under Contract F30602-75-C-0303. Dr. Jeffery W. Bell was the principal investigator and program manager for TSC. Mr. John Horn was the contract monitor and program manager for RADC.

The author thanks Mr. John Horn of RADC for his technical assistance and project support. In addition, thanks go to Mr. Warren Stone of TSC for his support in data base preparation and photographic work. The assistance of Miss Dona Reynolds in typing the report is also gratefully acknowledged.

SUMMARY

PROBLEM

Synthetic Aperture Radar (SAR) systems belong to the class of remote sensing devices whose purpose is to form high resolution images of terrain. The use of these systems in the 1980 time frame is expected to include on-line image change detection. This study was an exploratory development program with the purpose of establishing the fundamental capability of simulating SAR imagery of future systems for use in exercising change detection processors.

APPROACH

The heart of the simulation consists of the modeling techniques. They impact both the data base and the software. The emphasis in this simulation was placed on simulating the imagery produced by the SAR systems rather than the specific processes performed within the radar set. The approach was to model the significant characteristics of the targets and the radar required to produce realistic synthetically generated imagery.

The simulation software was developed and operated on a CDC 6400 computer. The simulation output from the CDC 6400 was written onto magnetic tape. The tape was then placed on a Varian 620/i minicomputer with a refresh memory and CRT, where the imagery was displayed. Hard copies of the imagery were produced by a vendor who made film plots from the tapes.

RESULTS

Simulated imagery was created in this study for two areas where ground truth and existing SAR imagery could be obtained. One of the areas is an Air Force test site known as Stockbridge, north of Rome, New York. The other is a dirt landing strip at Eglin Air Force Base, Florida. The simulated imagery compares extremely well with the actual imagery. Both simulated imagery and actual imagery are presented in the report to demonstrate the realism achieved in the synthetically generated imagery. Simulations were performed under a variety of conditions demonstrating the flexibility of the simulation program.

CONCLUSIONS

The major conclusion drawn from this study is that very realistic synthetically generated SAR imagery can indeed be produced for use in exercising change detection processors.

EVALUATION

The value of this effort to DoD's missions is that it has developed an algorithm which utilizes existing aerial photos and topographic maps to generate simulated radar images of a given area without the necessity or expense of an actual aircraft flight test. The approach was to formulate methods and software that are very general, flexible and modular. System parameters (altitude, depression angle, heading, multiple look factors, etc.) may be easily varied through inputs to the program. Data base updates may be accomodated simply by inserting the new data in the proper place on the data tape. The modularity permits software changes to be implemented with a minimum of work.

The primary motivation was to develop an algorithm capable of generating highly controlled simulated radar image pairs for quantitative evaluation of change detection equipment. However, the synthetic images have other potential applications to the DoD mission. For example, a preview of the type of image information that will be available from projected high performance (long stand-off, high altitude) radars may be obtained before these systems are actually flight tested. Such information could be quite useful for mission planning purposes. Simulated radar images could also be used as reference for correlation tracking or terminal guidance purposes.

John N. Horn

JOHN N. HORN
Project Engineer

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I. INTRODUCTION

PURPOSE AND OBJECTIVES

Synthetic Aperture Radar (SAR) systems belong to the class of remote sensing devices whose purpose is to form high resolution images of terrain. These ground-mapping radars provide an important and powerful technique for gathering military intelligence information through airborne reconnaissance missions. The use of such systems in the 1980 time frame is expected to include on-line image exploitation techniques. One of the major contenders is very likely to be an intelligence analysis technique referred to as comparative image change detection.

In order for such a change detection system to be operationally effective, it must necessarily preserve the inherent resolution and dynamic range of the image as provided in the radar signal processing system. In addition, it must be capable of correcting relative image distortions and supply the necessary processing required to optimize the completeness and accuracy of detection. To design an optimum change detection system for future radars requires a basic understanding of the anticipated changes in information content and appearance of the imagery as a function of scenario and radar parameter variations.

One approach to the gathering of such information is to simulate the imagery of future systems and create a series of simulated high resolution radar images under specified conditions. The operating parameters of the future systems are not yet available, yet it is generally agreed that the altitude, swath, and standoff capabilities will exceed those of present systems. Thus, given these new parameters and conditions, as well as aerial photos, topo map data, and radar imagery from present systems, it is possible for computer simulations to predict how the area in question would look and to generate representative imagery. A series of realistically computer generated high resolution SAR images could then be used in understanding how the probabilities of detection, recognition, and identification will depend on the system design parameters. This could lead to a set of design objectives for future reconnaissance exploitation equipment that is commensurate with the mission requirements.

This study was an exploratory development program with the purpose of establishing the fundamental capability of simulating SAR imagery of future systems for use in exercising change detection processors. To this end the objectives of program were twofold: (1) to develop algorithms and techniques for simulating high resolution imagery for future SAR systems using aerial photography, topographical maps, and SAR imagery from present systems as source data, and (2) to generate a set of simulated imagery under a variety of conditions to demonstrate the methods.

COMPREHENSIVE SUMMARY

In keeping with the goals of the study it was necessary to perform four major activities related to the simulation problem. These four areas are model development, data base generation, software architecture and programming, and the creation of simulated imagery. The approach taken was to formulate methods and software that are very general, flexible, and modular. Thus, by generating new data bases and varying the system parameters, imagery from a variety of scenarios can be simulated. System parameters are easily varied through inputs to the program, and data base updates are made by inserting the new data in their proper place on the data tape. Because of the software modularity, programming changes can be implemented with a minimum of additional work.

The heart of the simulation consists of the modeling techniques. They impact both the data base and the software. The emphasis in this simulation was placed on simulating the imagery produced by the SAR systems rather than the specific processes performed within the radar set. The approach was to model the significant characteristics of the targets and the radar required to produce realistic synthetically generated imagery.

Target modeling consists of two major aspects. They are the geometry and the radar reflectivity. Modeling the radar reflectivity includes the average effective target cross section and a statistical fluctuation model. The geometric modeling accounts for location, orientation, and shape of the target.

The radar system modeling accounts for the system parameters, such as wavelength, resolution, aspect angle, and depression angle, etc.

Other features taken into account are the shadowing, impulse response of the radar system, non-coherent integration, and noise.

The data base is generated from several basic sources of information. The geometric data are obtained from photos, maps and charts, blue prints (if available), and existing SAR imagery. This information is extracted by an operator interacting with a graphic digitizer. The reflectivity data are determined from the photos, SAR imagery, published measurement data, and experience.

There are several major elements to generating the data base. The first is a registration process which defines and locates the coordinate system to be used. In the second, target information treated as line segments or points is incorporated into the data base. This includes contour data, planimetric features, pathways, and point targets. The height information and reflectivity are assigned to each feature after it has been graphically digitized. The third element of data base generation is the digitizing of structures, which are treated different from features represented as line segments or points. Once the perimeter of the structure is digitized and entered, the height and reflectivity are assigned. Lastly, a set of routines are used in plotting, printing, and merging the data base.

The simulation software was developed and operated on a CDC 6400 computer. The simulation output from the CDC 6400 was written onto magnetic tape. The tape was then placed on a Varian 620/i minicomputer with a refresh memory and CRT, where the imagery was displayed. Hard copies of the imagery were produced by a vendor who made film plots from the tapes.

The simulation software operates in a very straight forward manner by first creating the synthetic imagery as represented by the data base and then incorporating the sensor characteristics and target fluctuations. The scene is synthetically created from a set of features sequentially introduced in the following order: First planimetric features are outlined, then the contours are added. Pathways are layed out next, and structures follow. Point sources are included last.

After the basic scene is created, the shadowing is performed. The impulse response of the radar is then imposed on the imagery. This is

followed by the target fluctuation and non-coherent integration. The addition of radar noise is the last operation in the simulation.

Simulated imagery was created in this study for two areas where ground truth and existing SAR imagery could be obtained. One of the areas is an Air Force test site known as Stockbridge, north of Rome, New York. The other is a dirt landing strip at Eglin Air Force Base, Florida. The simulated imagery compares extremely well with the actual imagery. Both simulated imagery and actual imagery are presented in the report to demonstrate the realism achieved in the synthetically generated imagery. Simulations were performed under a variety of conditions demonstrating the flexibility of the simulation program.

The results of this study lead to the conclusion that the methods described herein can be used effectively to produce realistic simulated SAR imagery.

II. SIMULATION MODELS

Modeling is the central issue in the simulation since both the data base and the software are designed around it. Two classes of models are required for the simulation. They are target models and models of the radar system. The target models account for the basic scenery in the imagery, whereas the radar models produce the sensor characteristics visible in the actual imagery. The modeling techniques used in this project are the direct result of other studies conducted by Technology Service Corporation (TSC) [1,2].

TARGET SCATTERING MODELS

There are two aspects to target modeling that must be included. The first is the scattering model which produces the intensity; the other is the geometric model which accounts for shape, size, and orientation. The scattering model has both a deterministic element and a statistically element. The deterministic part defines the average effective cross section. The statistical part describes the fluctuation of the target cross section.

The geometric modeling is carried out basically with points representing vertices or ends of line segments. These points are therefore used in outlining or locating the various features in the scene. Data base generation is mainly concerned with digitizing these points and creating data files. Therefore, this subject will be covered in greater detail later. The emphasis here is on target scattering models.

Natural Terrain

Natural terrain consists of relief and a material type exhibiting a specific cross section coefficient. Relief is modeled with contours that are digitized and entered into the data base. The scattering process is modeled with a mathematical formula.

Scattering from terrain is a highly complex phenomenon. The received signal is primarily a function of the terrain type, foliage type, water content, encounter geometry, and the radar parameters of wavelength, polarization, and resolution cell size. Measurement data on terrain scattering are usually inconsistent because of the variable nature of

many of these factors. Moreover, most investigators consider terrain scattering to be clutter--that is, an effect that degrades the detection of other desired targets. In the case of clutter, the primary interest is in the gross behavior of the scattering, not in the microscopic detail necessary to model a display.

Since detailed information was not available, we implemented rather simple models for terrain scattering. The particularly simple model that we chose to implement incorporates two important effects: amplitude dependence as a function of local grazing angle and shadowing. Both effects can be derived from the elevation profile of the terrain (contours) and the encounter geometry.

If a given resolution cell on the ground is not shadowed, it is logical to define the ensemble averaged radar cross section (RCS) as a function of the angle the radar line-of-sight makes with the local normal to the ground. This can be represented by a sine function or some other more complicated function. Nevertheless, since we are interested in computationally simple algorithms, we can make small angle approximations. This yields the following simple RCS model:

$$RCS \approx \gamma \Delta A(\delta + \varepsilon) \qquad (1)$$

where γ is the normalized radar cross section per unit area, ΔA is the area of the resolution all, δ is the depression angle of the radar, and ε is the local slope in elevation.

<u>Homogeneous Planimetric Terrain Features: Fields, Woods, Urban Areas</u>

These regions are modeled in virtually the same manner as natural terrain with a couple of exceptions. These terrain features are defined by their perimeters and then individually assigned an RCS and given a height. The height of each region is then added to the local elevation profile from the contours. The RCS also differs from the remaining natural terrain, all of which has the same value. The values of γ used in the simulation are linearly related to published data. Parameters ΔA and δ in Equation (1) are program inputs. Whereas, ε is computed from the local elevation profile.

Fields are simply defined by a perimeter and then assigned a value of γ. Generally no height is given to a field. Wooded areas are given a height as well as a value of γ. This height produces two necessary effects. One is the shadows from the far edge of the field. The other is the leading edge return from the near end of the field. This bright return results from the sudden change in the local slope where the height is added to the elevation profile.

In areas containing a high density of relatively small buildings (say, no longer than 10 resolution cells in extent), each building need not be modeled individually. Group descriptions are sufficient. Thus, homogeneous urban regions, such as residential areas composed of buildings all of which are nearly the same size and height, are modeled using the approach. The street pattern is then overlayed, as discussed next.

<u>Pathways</u>

Features considered here to be pathways are roads, streets, highways, and also rivers. They are all modeled as connecting line segments (lineal features) with an assigned width. As a rule, such pathways exhibit no radar return because of the surface smoothness. They are therefore assigned a γ value near zero in the simulation.

It is true, however, that a bright return is often visible in SAR imagery from the sides of these features. This results from the center dividers, gutters, structures, embankments, etc. in the case of roads; and from dikes and the discontinuities along the banks in the case of river beds. These bright returns are modeled by assigning larger values of γ to the sides of pathways.

<u>Structures</u>

<u>Significant Buildings</u> - Buildings that require individual modeling are very large buildings (occupying 20 or more resolution cells) found in any surroundings, or relatively isolated buildings (with extents of 10 resolution cells or more) in low clutter backgrounds, such as open fields. Such buildings were modeled as extended scatterers having both specular and diffuse scattering properties. Specular scattering is much in evidence in

radar imagery. Significant "diffuse" scattering can be seen at large angular displacements (as large as 45°) from broadside. The source of these returns cannot be specifically identified due to the wide variety of building surfaces, construction materials and geometry. Possible sources of this "diffuse" return include departures of building face from smooth, flat plane reflector and irregularities such as windows, ledges, columns, etc.

In view of the complex nature of building faces, the approach used is to consider the dominant effects of flat plate scattering and dihedral returns. We employ a three parameter empirical scattering model which is calibrated and qualified by comparison with actual radar data on specific buildings. The following model gives a diffuse return, as well as a large specular return whenever the radar is near the plane perpendicular to the building face:

$$RCS(\theta) = \begin{cases} \Delta A(\beta[1 - (\theta/\theta_c)^2] + \gamma\cos\theta), & |\theta| < \theta_c \\ \Delta A\gamma\cos\theta & \text{otherwise} \end{cases} \quad (2)$$

The azimuthal angle of the radar relative to the outward building face normal is represented by the variable θ. ΔA is the area of the building face centered within the resolution cell. The three empirically determined parameters are β, γ, and θ_c. The normalized diffuse cross section is represented by γ, β is specular gain, and θ_c is the lobe width of the specular return.

Cylinders - Due to the variety and complexity of the scattering from cylinders (modeling storage tanks, circular antennas, etc.) a simple, empirical model is again employed. Given the center of the base and the diameter of a cylinder, radar returns are distributed around the circumference of the tank with intensity falling off as the cosine of the angle between the outward circumferential normal and the projection of the line-of-sight onto the ground plane. We apply our 3-parameter model, empirically scaled, in a piece-wise fashion to each part of the circumference falling within one resolution cell. The tangent plane to each part provides the orientation in azimuth.

Point Sources

Point sources are those targets that are smaller in size than a radar resolution cell, yet produce a very bright return. As a rule, targets represented by point sources saturate the cell they occupy depending of course on the statistical variations of the signal. These targets are modeled by a location on the earth's surface and a radar cross section.

TARGET FLUCTUATION MODEL

The target scattering models we have discussed model the average radar cross section. However, in actual SAR imagery, there is a cell-to-cell fluctuation that is caused by the nonhomogeneous nature of radar targets (and coherent break up in coherent systems). We simulate this effect by generating random intensities at each cell according to a specified statistical distribution where the mean value is determined by the average radar cross section of that cell. In this project, we assumed the intensity to be exponentially distributed (Rayleigh amplitude distributed). Other valid statistical distributions are Rice and log-normal, depending on the particular conditions and scattering phenomenon.

RADAR MODELS

System Parameters

Parameters specifying the radar position, such as altitude, range, depression angle, and aspect angle are modeled using geometry and transformations. These parameters are treated as inputs to the simulation program. The wavelength of the radar system is not explicitly modeled. Rather it is embedded in the scattering and fluctuation models, as well as in the resolution of the system. Resolution is modeled by specifying the cell size in both range and azimuth, as viewed in the imagery. These two cell dimensions are inputs to the program.

Shadowing

Beginning at near range and proceding along a row of constant azimuth, the slope of the shadow is computed. At each grid point in the elevation matrix, the elevation is compared with the elevation of the shadow (which is easily obtained from the slope of the shadow). There are two options:

<u>elevation > shadow</u> - The portion of the object contributing to this grid element is at least partially visible by the radar. Do not alter the reflectance but compute a new shadow.

<u>elevation < shadow</u> - The portion of the object contributing to this grid element is totally shadowed. Replace the reflectance at this grid element in the reflectance matrix by zero.

We do this for all rows of constant azimuth that are contained within the frame. Since there can be structures or terrain features outside the area covered by the displayed frame that can cast shadows inside the displayed frame, the frame actually processed must be larger in range by an amount equal to the length of the shadow cast by the highest feature outside the displayed frame.

Impulse Response

A system impulse response produces target spreading and introduces a sidelobe structure to the imagery. Both of these effects cause a degradation in effective resolution. Although found in both the range and azimuthal dimensions, the severity is not the same. The impulse response in the two dimensions result from different phenomena, such as the radar waveform in the range dimension and doppler filtering in azimuth. However, both impulse responses are generally akin to the function $(\sin x/x)^2$, which has regularly spaced sidelobes and nulls.

Since this function represents the average power value, the regularity is not observed in real imagery because of the statistical fluctuations. Thus, our model of the impulse response actually accounts for only the average monotonically decreasing sidelobe level. The statistical fluctuations are then imposed using this average sidelobe level as the effective average radar cross section.

Non-Coherent Integration

Non-coherent integration is often performed on imagery from SAR systems to reduce the effects of the statistical fluctuations. This can be done in several ways. One way is to average images obtained at slightly

different frequencies. Another is to average images obtained from slightly different azimuthal angles. A third method is to merely average a set of contiguous resolution cells and replace the averaged value in each of the pixels. This is a common approach and can be used if only one image is available for averaging. However, it suffers the loss of resolution by a factor related to the number of cells that are averaged.

We simulate all three types of integration. The first two are simulated in the same way: A number of random samples for each pixel are drawn from the fluctuation distribution and averaged. The pixel is then assigned the averaged value. In simulating the averaging of adjacent resolution cells, we create an image and then perform the cell averaging the same way it is done in actual systems.

Noise

In this simulation program, noise is modeled by adding a random number to the fluctuated value of the target radar cross section. The random number can be drawn from any statistical distribution describing the noise. A Gaussian distribution is probably a good approximation and could be used. Experience has taught us that there is virtually no visually perceptive distinction between Gaussian noise and uniform noise. Thus, because of the simplicity involved we modeled the noise with a uniform distribution.

III. DATA BASE GENERATION

APPROACH

Aerial photography, USGS maps, on-site ground photography, and sample imagery were used to produce the digital data base for use in its radar simulation. A Graf-Pen digitizer is used to extract data from these analog formats and convert it to digital form. Data base generation consists of setting up reference points and line segments, and defining structures.

Data editing and entering auxiliary information is performed through the use of a "menu board," which can be arbitrarily defined and arbitrarily located. Our menu board is shown in Figure 1. Communication between the system and the user via the menu board is performed by digitizing a point in a menu square. The user can select functions to:

1. Set flags
2. Input alphanumeric constants
3. Erase the last digitized point or group of points
4. Select an area to be plotted
5. Limit the valid area of the digitized surface as a check on spurious errors
6. Associate a point on a photograph or a map with the corresponding point on a previously digitized map
7. Transform Graf-Pen units to user defined system
8. Store actual data for later use.

By specifying the bounds of the menu board on the Graf-Pen tablet and the size of each entry square composing the board, a digitized point can be determined by the digitizing software as representing some instruction or simply representing the coordinate of some object. For example, the elevation of a 50' contour line can be specified by first digitizing a point on the "5" square, then a point on the "set alt" square.

1	2	3	4	5
6	7	8	9	0
CLEAR NUM		SPECIAL END SET ALTITUDE SET HEIGHT SET WIDTH	SET ALTITUDE INCREMENT CENTER PICUTRE	END SECTION
END CONTOUR SET PARALLEL STREET	CLEAR SECTION	RANGE ON	RANGE OFF	CLEAR ALL NO PARALLEL STREET
CLEAR MARK	NO. OF TRANS. SET INTENSITY ROOF CODE	SET SCALE SET BUILDING #	COORD. TRANS.	SET POINT NUMBER
A	B	C	D	E
F	G	H	I	J
K	L	M	N	P
Q	R	S	T	U
V	W	X	Y	Z END BUILDING

Figure 1. Menu Board

SOFTWARE PROGRAMS

Registration

The first step in data base generation is registration. The user-defined coordinate system used in the final data base is the Mercator Metric System. The software creates a grid from these tic marks in Graf-Pen units and then performs a least-squares fit from Graf-Pen units to the actual Metric coordinates. (This method is superior to simply taking points along the top and side edge of the map, since the edges of USGS maps are not always in the form of straight lines.) Six constants are generated to convert digitized units in X and Y into the relative metric coordinate system.

After these constants have been derived, high-confidence reference points are designated and digitized. A least-squares fit is performed between the digitized points and the corresponding points in the reference file to create the necessary conversion constants. Then data can be referenced to the Metric coordinate system.

The program produces a grid system across the map (in Graf-Pen space) and finds the parameters for the transformation from Graf-Pen space to the user coordinate system. The digitized reference points are then transformed to user coordinates. The entire process is repeated several times to improve the accuracy of the reference point coordinates. The program averages the resulting coordinates of each point.

Segment Program

The second step is to create a featural file for points and line segments. A user places a new map, photograph, or image on the tablet and digitizes a subset (containing three or more points) of the previously defined reference points. One chooses all reference points which are clearly discernible, and labels them exactly as they are labeled on the reference point file. For each reference point being digitized, the operator inputs the identifying number and letter of the section containing the point and a number identifying the location of the point within the section.

A scale and X and Y "offsets" are input for the file so that the operator can make minor changes in the location of features that are manifestly slightly misplaced with respect to features in another file. The range of the map is input such that points outside the range are ignored.

Next the program creates the featural file. First, the characteristics of the feature or object are specified via the menu board and stored in the file. Then the X, Y, Z information is digitized and stored. Lastly, the level of intensity representing the average radar cross section is assigned to the feature by the user.

Structures

The third step is to determine the placement of polygonal structures. The first step performed is the calculation of the coordinate transformation parameters and the specification of scale, X and Y offsets, and range values exactly as described for the previous program. A building is assigned an identification number. The placement is determined by specifying four points (two of which may be coincident) on the base of the structure. If the structure is aligned parallel to a street, the parallel street can be specified by two points and the structure rotated such that one side is exactly parallel to the street.

A roof code is entered for the building which is related to the average radar cross section of the building roof.

Merging and Checking

Four utility programs have also been developed to aid in the data base generation process. The first of these merges each of the individual featural files into one large data base file. The second creates a plot of the information described on each featural file. The third utility program allows the addition of hand calculated reference points to the reference point file, and the final utility program creates a printout of digitized data.

THE GRAPHIC DIGITIZER

The Graf-Pen Digitizer system consists of a 30-inch glass tablet, a control unit, a pen with spark gap, a keypunch interface, and an IBM 029 keypunch machine. Sparks are created by manually depressing the spark generator at the pen point. The ultrasonic waves created by the spark are then sensed by the acoustic microphones at the edges of the tablet. The arrival time of the acoustic wave at a microphone determines the distance from the pen to the microphone. A signal is then sent to the keypunch interface giving the digitizer coordinates of the pen. The keypunch then punches eight columns in BCD format, four columns for X and four columns for Y.

The published accuracy of the digitizer is reported to be 0.007 inches. We compiled our own statistics of Graf-Pen measurements with the pen stationary in free run mode [2]. The resultant standard deviation was between 0.005 and 0.006 inches. A second similar experiment was performed to test the ability of a human operator to locate the same point on independent trials with the Graf-Pen. The resultant standard deviation was computed to be between 0.012 and 0.020 inches.

The 24000 series USGS maps are reported to be accurate to only 40 feet horizontally. This is however, an absolute, global statistic. Within a distance of several hundred feet, the relative position of map features is much more accurate. However, considering the probable human error of 0.02 inches in locating a point with the Graf-Pen and the ground truth is 40 feet, independent of the location of the point.

The orientation of a directional discrete scatterer can have a very significant error due to the 40 foot displacement error. For example, in the case of a square building 100 feet on a side, mislocating one corner by 40 feet would cause an error in building orientation of nearly 22°. Therefore, as most buildings are aligned parallel to streets and roads, the extreme points of streets, say 1200 feet apart, are entered into the data base to define the orientation within 2 degrees of all buildings referenced to that street.

DATA BASE EXAMPLES

The source data in the form of maps, photographs, and blue prints used in digitizing the data bases for the Stockbridge and Eglin areas are shown in Figures 2 to 7. Plots of the digital contour and featural data bases for both areas are presented in Figures 8 to 23. Reference points appear in the data base plots as plus signs.

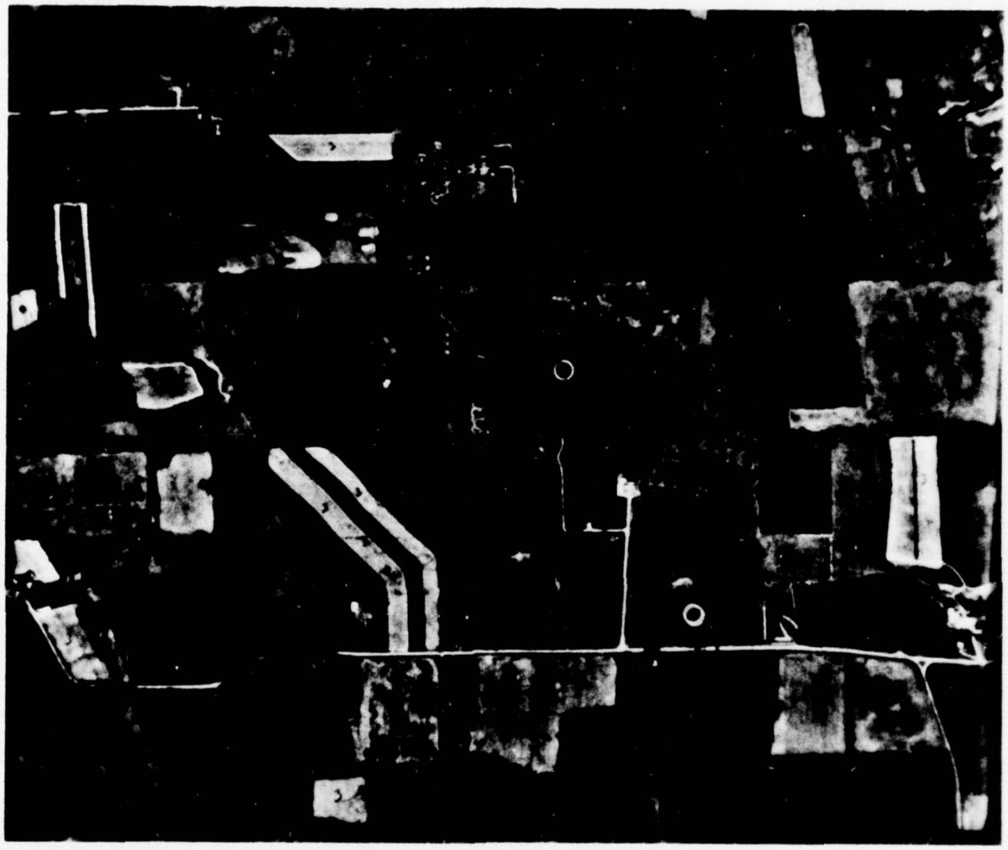

Figure 2. Photograph of Stockbridge Target Area

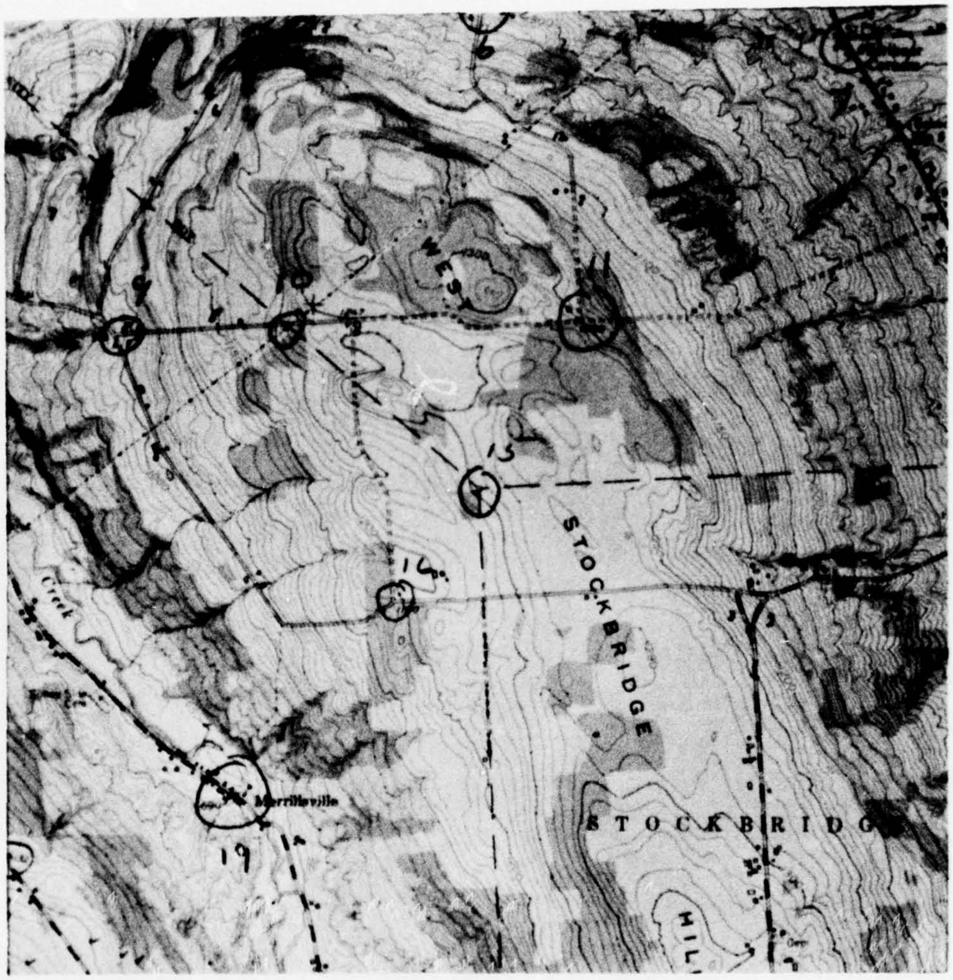

Figure 3. USGS Map of Stockbridge Target Area

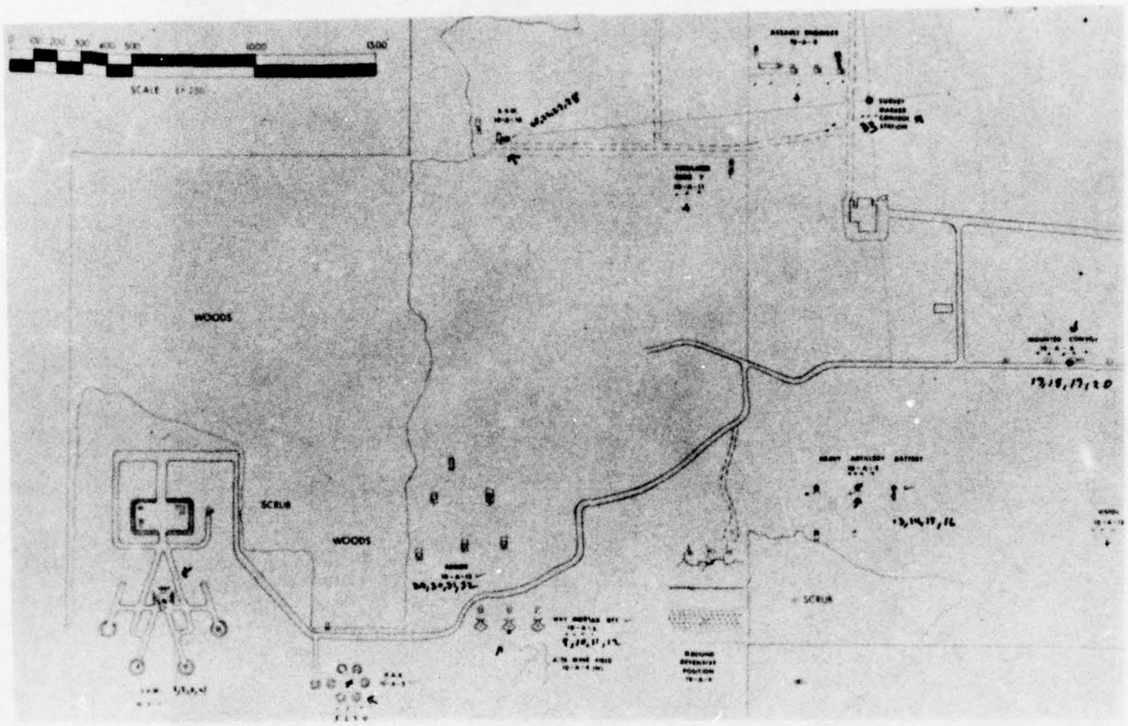

Figure 4. Blue Prints of Stockbridge Targets

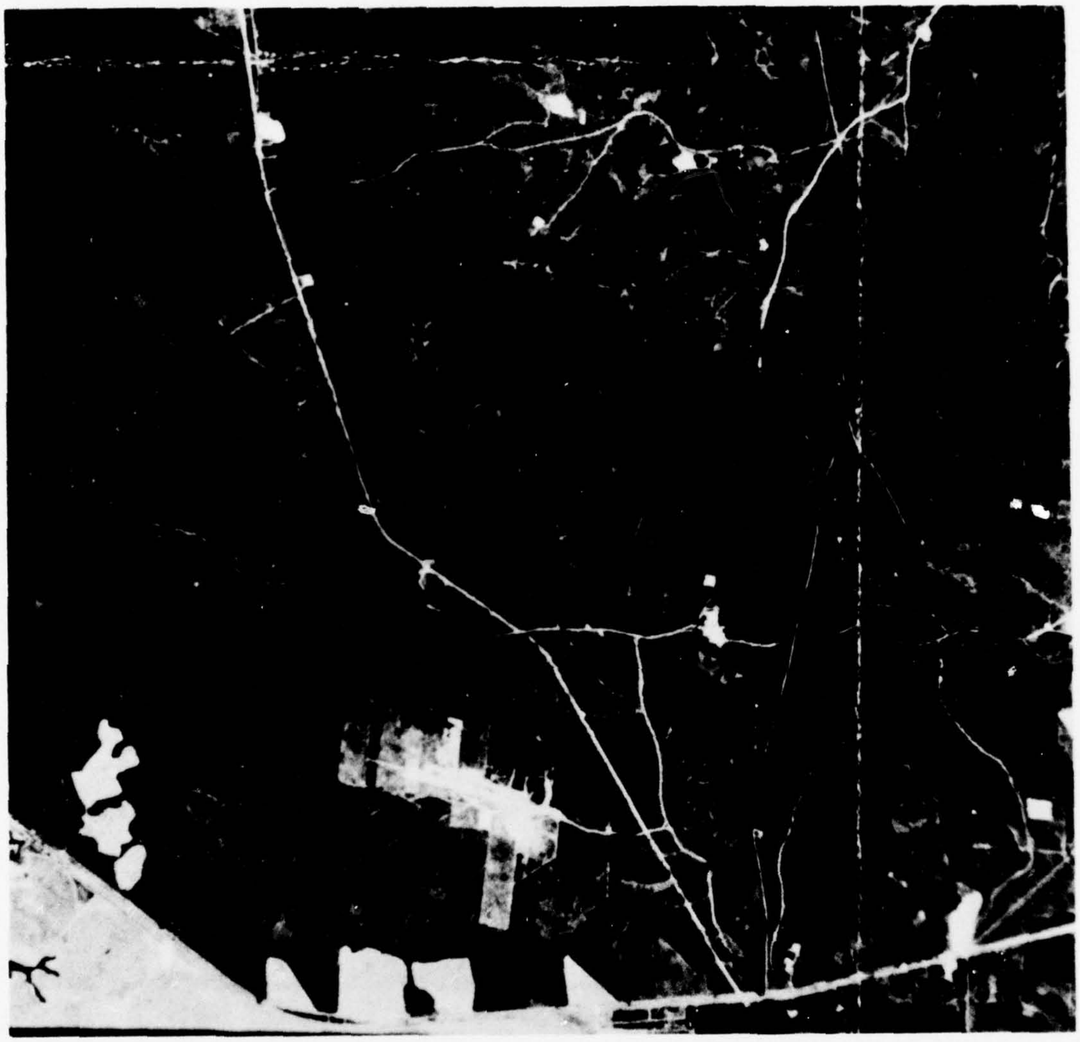

Figure 5. Photograph of Eglin AFB Target Area

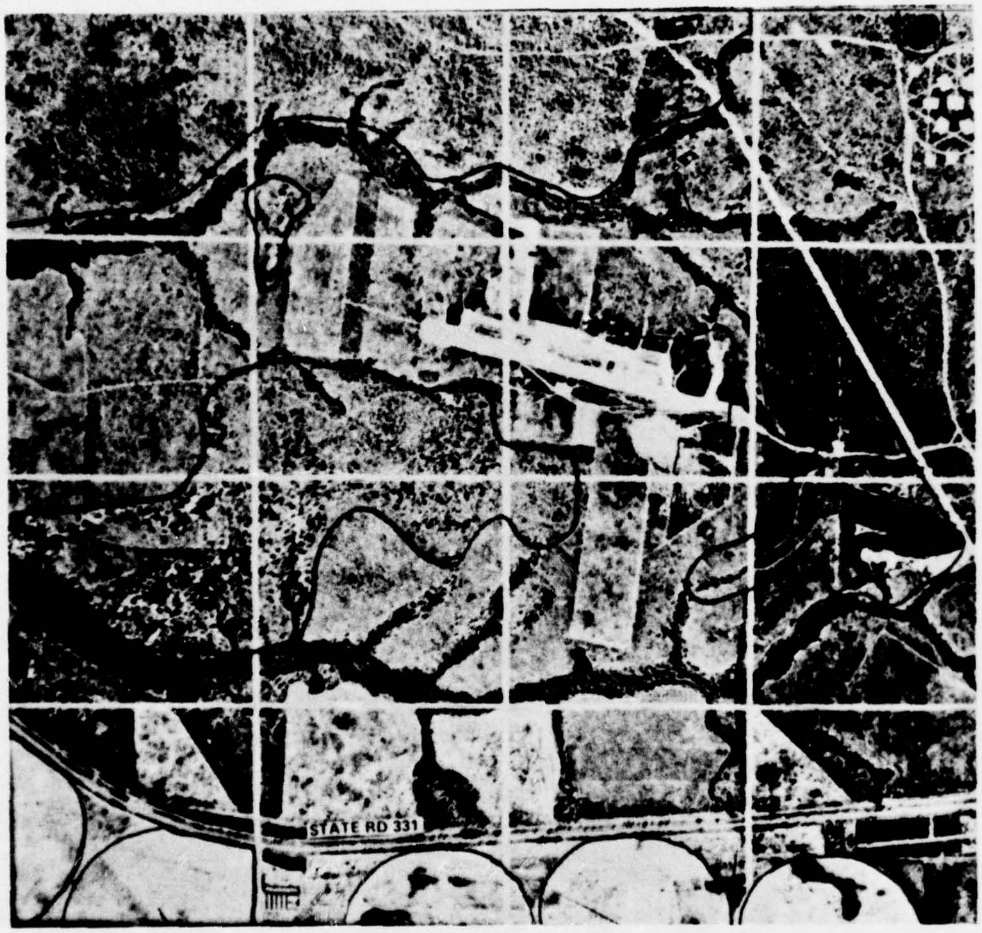

Figure 6. Planimetric Source Data of Eglin AFB Target Area

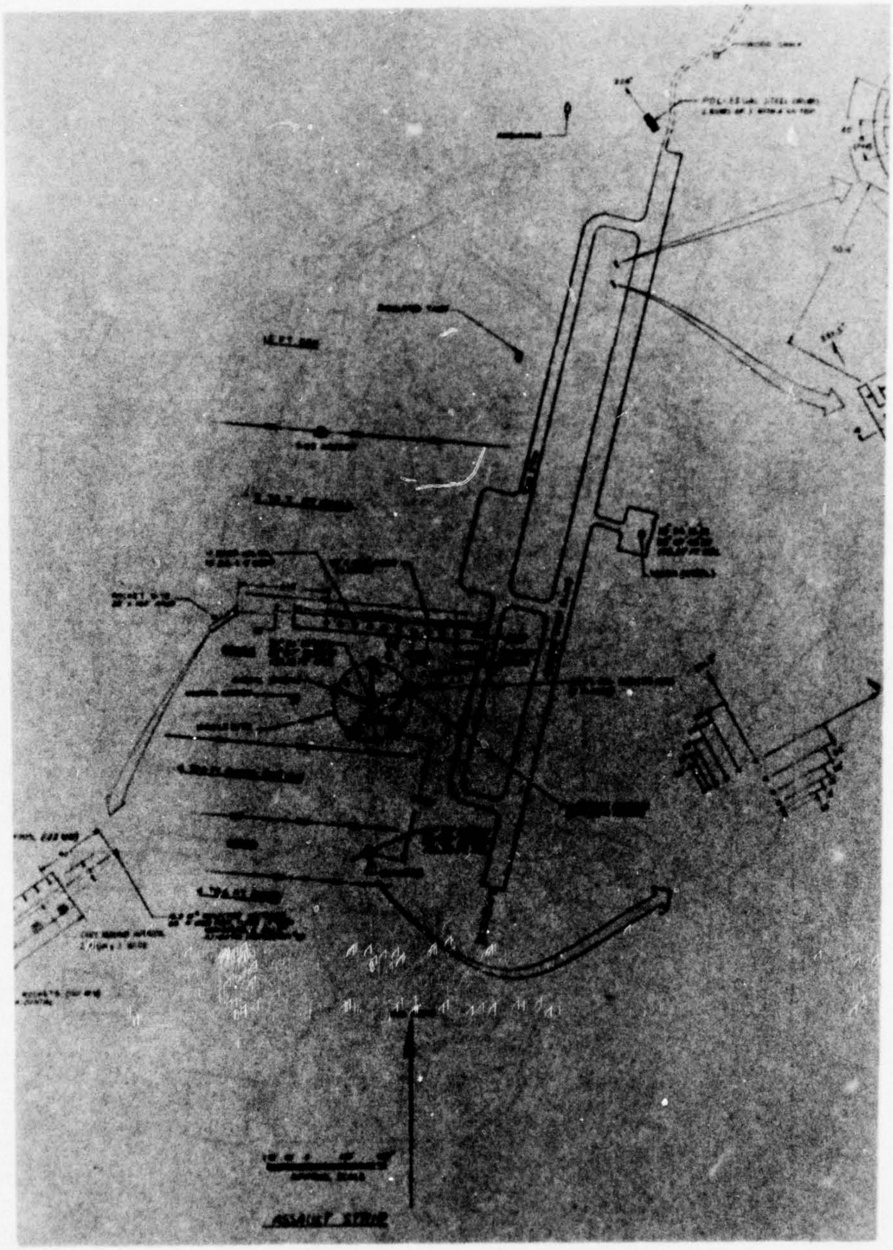

Figure 7. Blue Print of Eglin AFB Targets

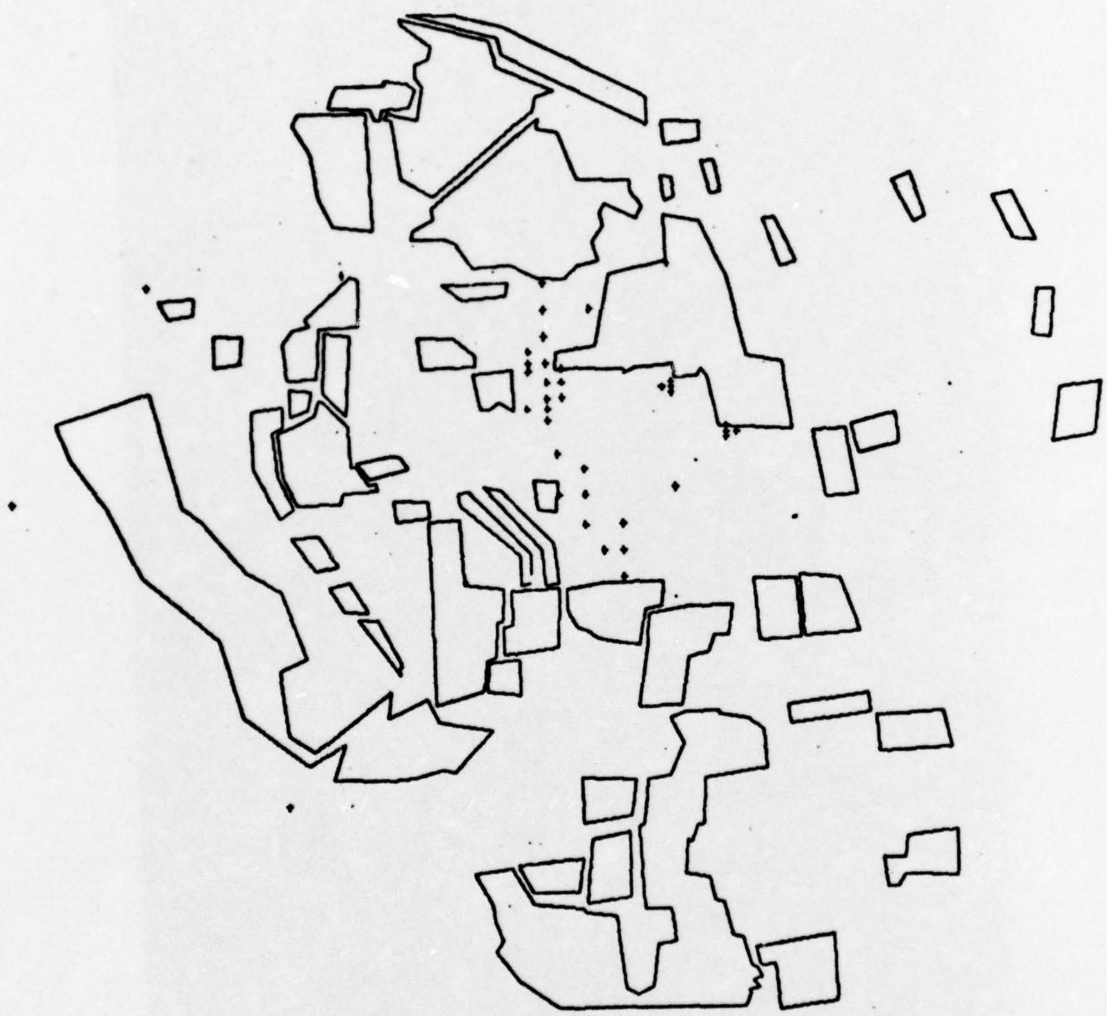

Figure 8. Computer Plot of Stockbridge Field Data Base

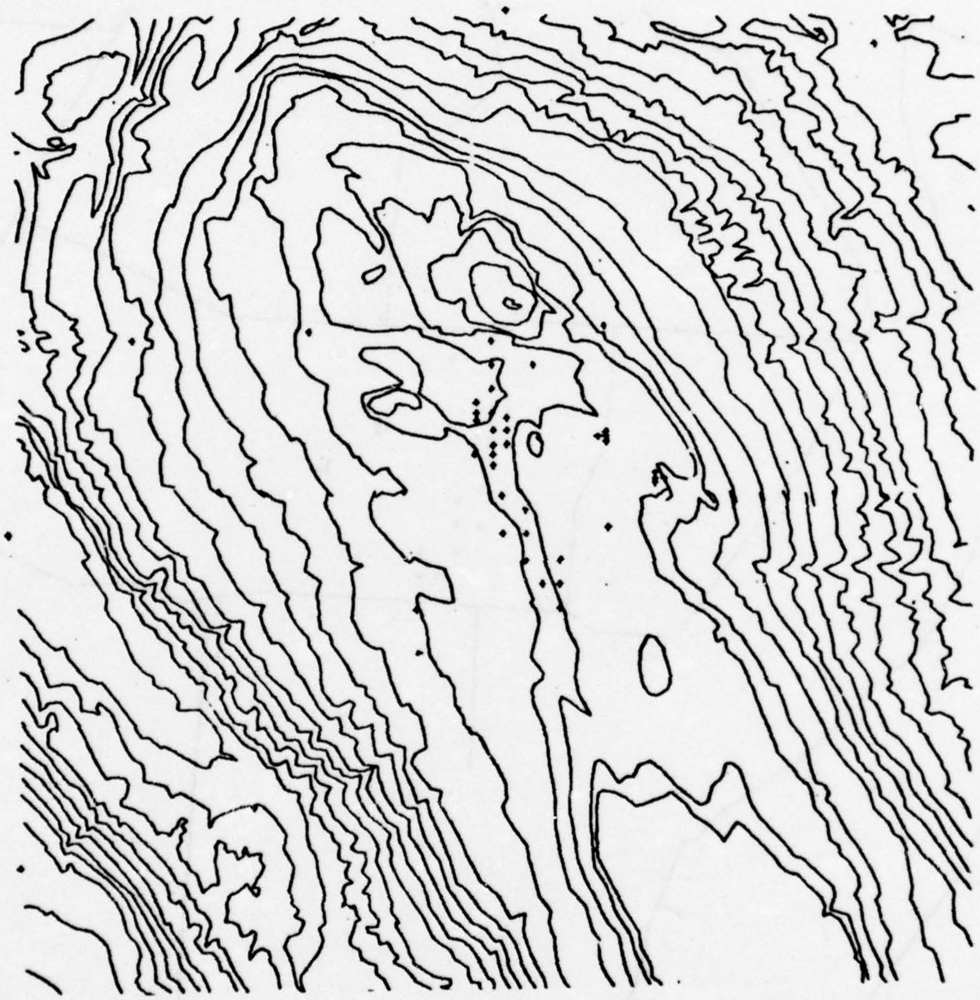

Figure 9. Computer Plot of Stockbridge Contour Data Base

Figure 10. Computer Plot of Stockbridge Highway Data Base

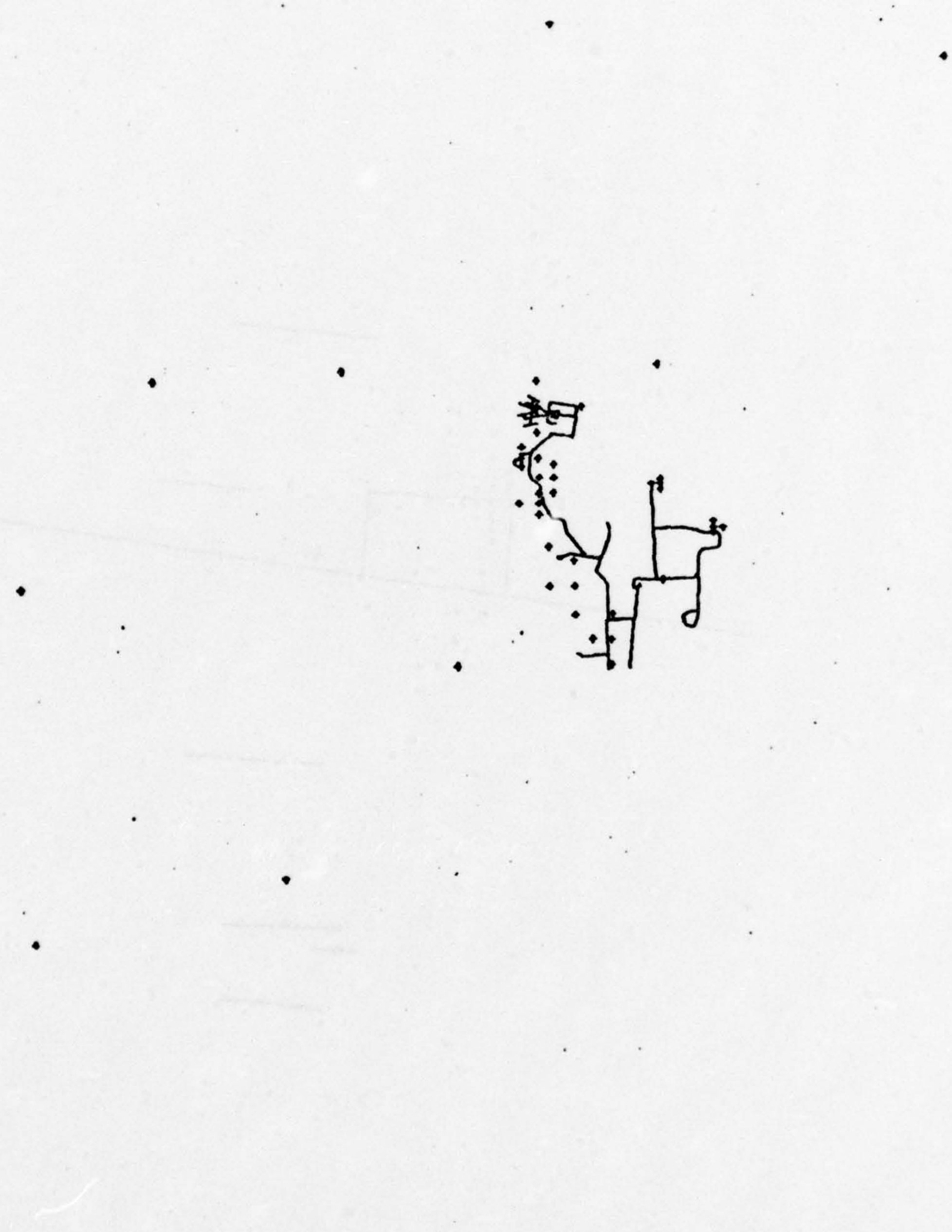

Figure 11. Computer Plot of Stockbridge Street Data Base

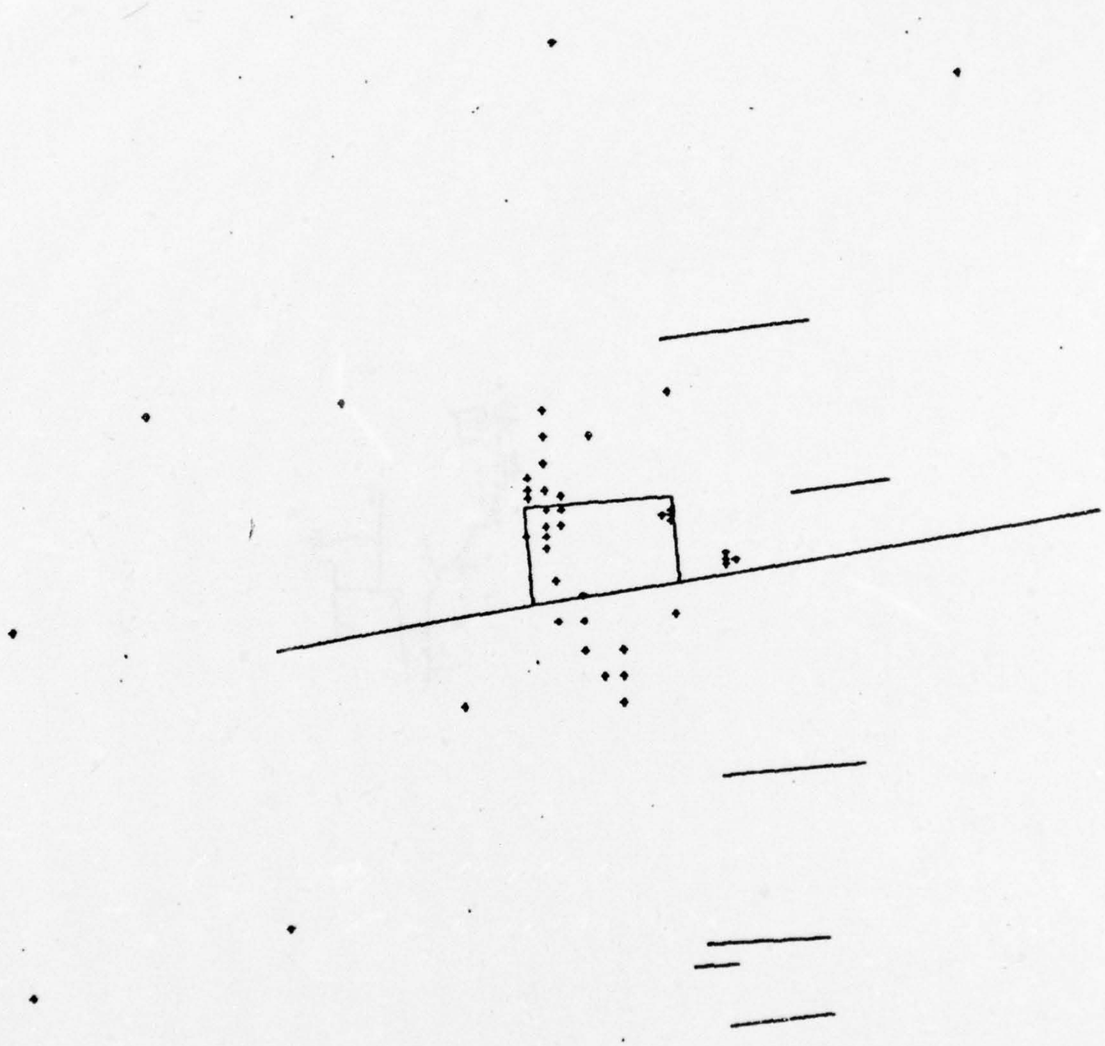

Figure 12. Computer Plot of Stockbridge Tree Line Data Base

Figure 13. Computer Plot of Stockbridge Target Data Base

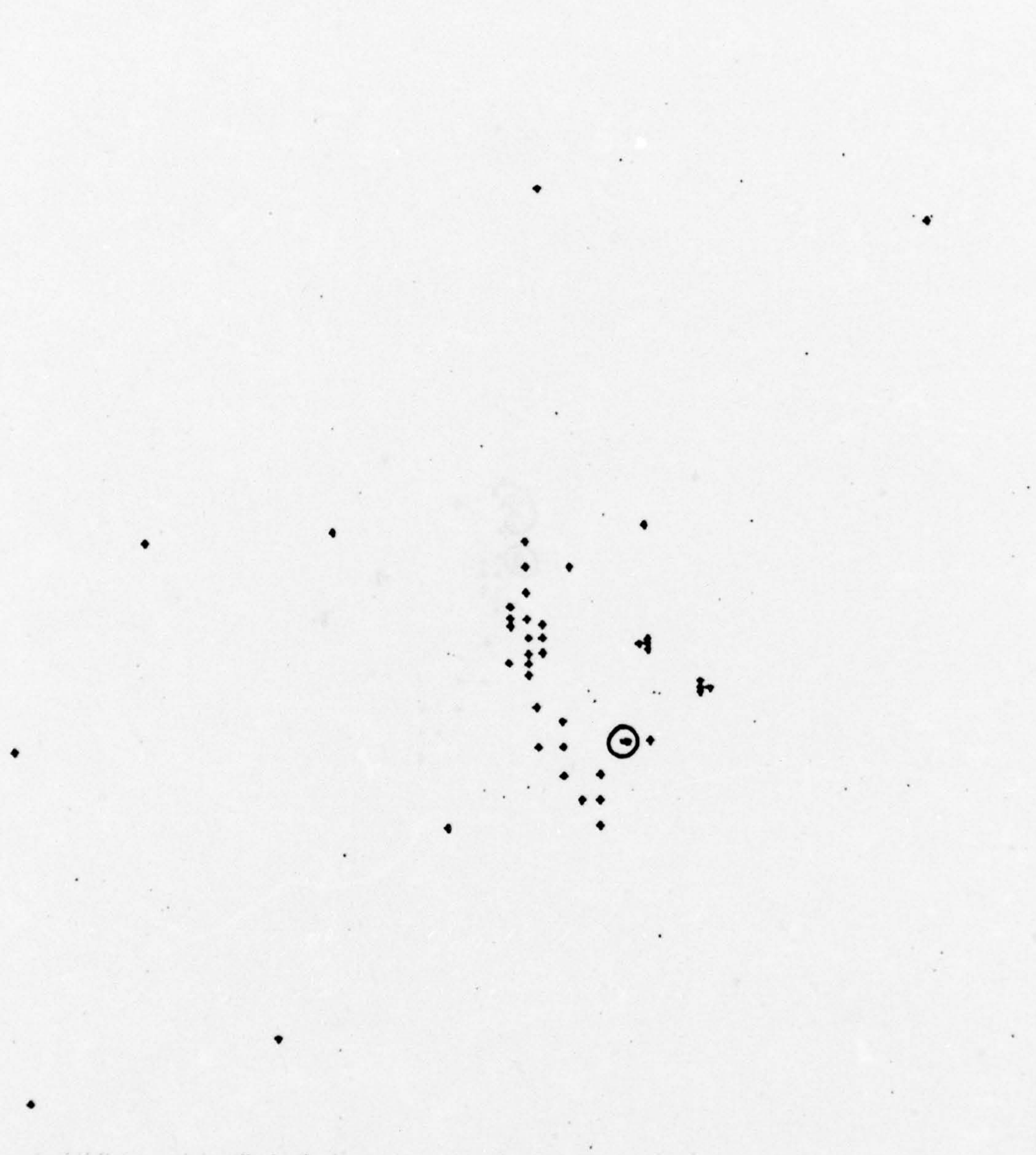

Figure 14. Computer Plot of Stockbridge Building Data Base

Figure 15. Computer Plot of Stockbridge Antenna Data Base

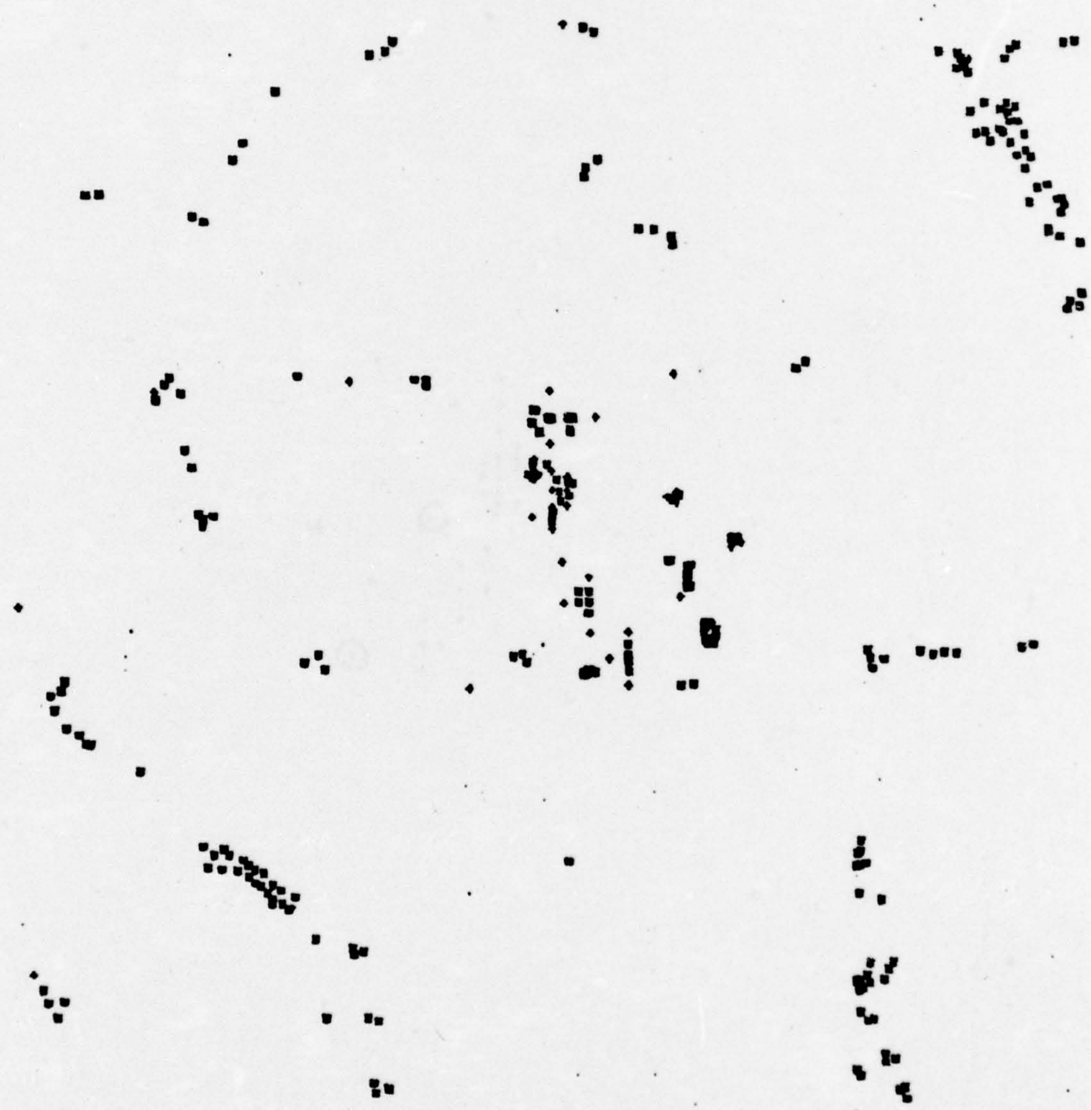

Figure 16. Computer Plot of Discrete (Point) Scatterers
Data Base Extracted From USGS Maps

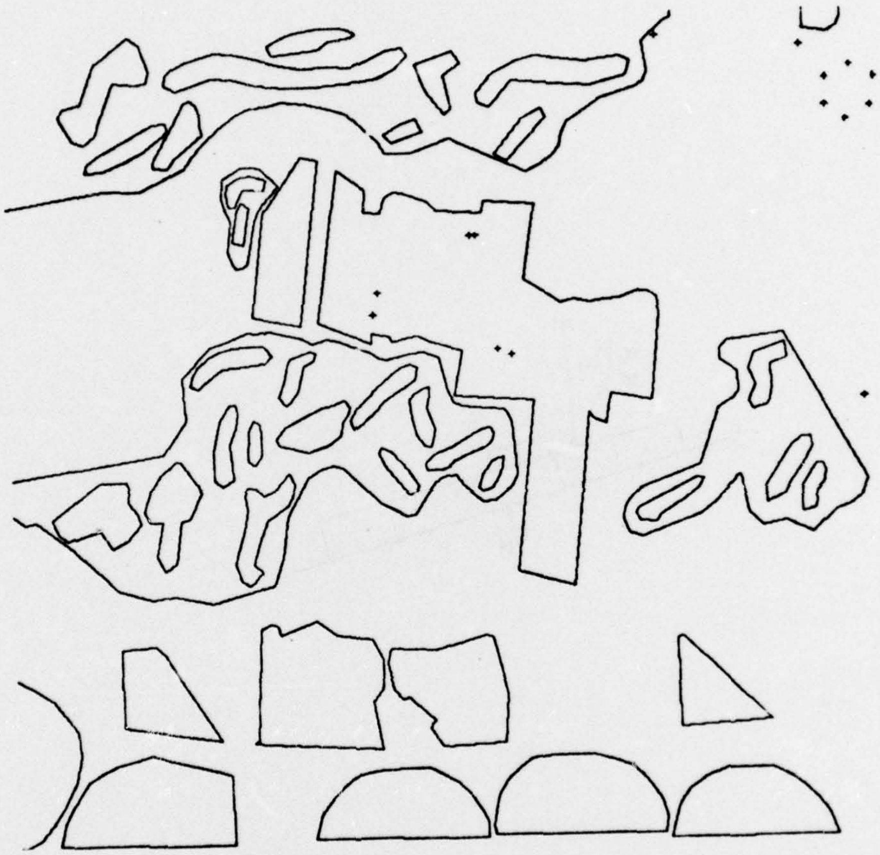

Figure 17. Computer Plot of Eglin Field Data Base

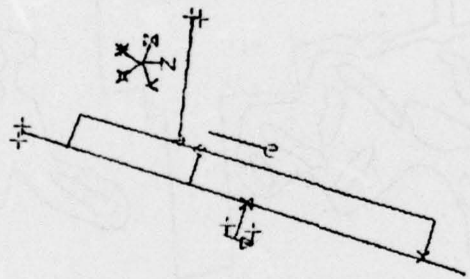

Figure 18. Computer Plot of Runway Data Base

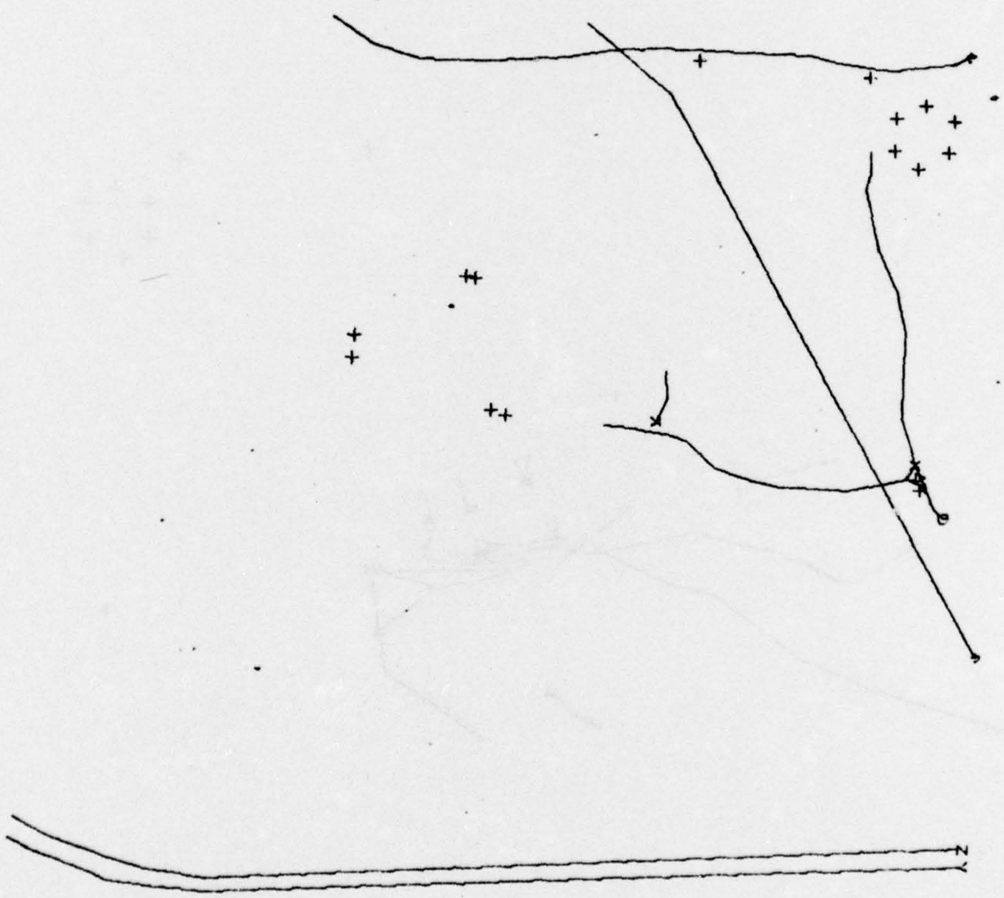

Figure 19. Computer Plot of Eglin Hignway Data Base

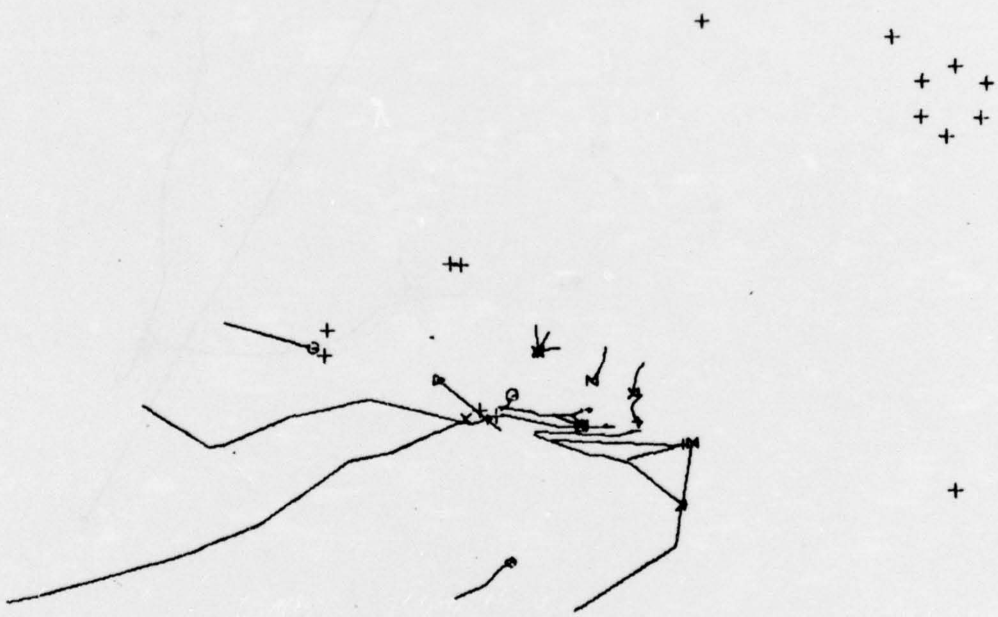

Figure 20. Computer Plot of Eglin Dirt Road Data Base

Figure 21. Computer Plot of Eglin River Bed Data Base

Figure 22. Computer Plot of Eglin Building Data Base

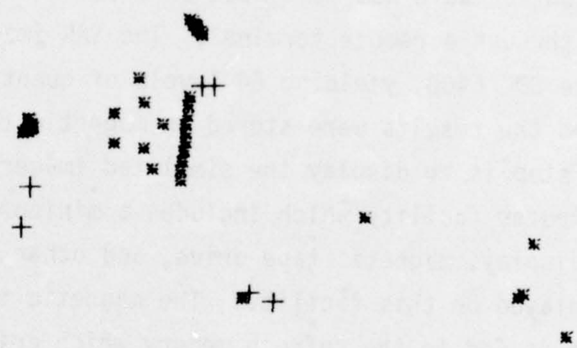

Figure 23. Computer Plot of Eglin Point Target Data Base

IV. SIMULATION PROCEDURES AND SOFTWARE

INTRODUCTION

The creation of simulated SAR imagery as reported in the document consists of four major steps. The first is the generation of the simulation data base. The processes and procedures utilized in generating the data base were explained in the previous section; and examples were provided to show the results.

The second major step is to carry out the simulation. All of the actual simulation software was developed on a CDC 6400 computer to which TSC has access through a remote terminal. The SAR imagery simulations were performed on the CDC 6400, yielding 64 levels of quantized intensity information, and the results were stored on magnetic tape.

The third step is to display the simulated imagery on a CRT. TSC has an in-house computer facility which includes a minicomputer, a refresh memory, a CRT display, magnetic tape drive, and other peripherals. The imagery is displayed on this facility. The magnetic tape is read in and the information is fed to the refresh memory which drives the CRT.

Several iterations may be performed on steps two and three until a satisfactory set of images are produced. The last step is to create hard copies of the imagery. The information on magnetic tape is sent to a vendor who produces film plots of the simulation. These plots are then taken to the TSC photolab where the films are developed and prints are made.

The heart of this study was the development of the simulation software. This section is devoted to a discussion of the software produced and used in simulating the SAR imagery.

SOFTWARE OVERVIEW

The main aspects of the simulation software are depicted in the flow diagram of Figure 24. (A Software Documentation Package gives the complete information [3].) Three major loops are shown. One involves processing the data in vertical strips. The reason for this is that the simulated imagery is composed of 480 pixels in each dimension, for a total of about 230,000 pixels. Because of the memory constraints on the CDC 6400 computer

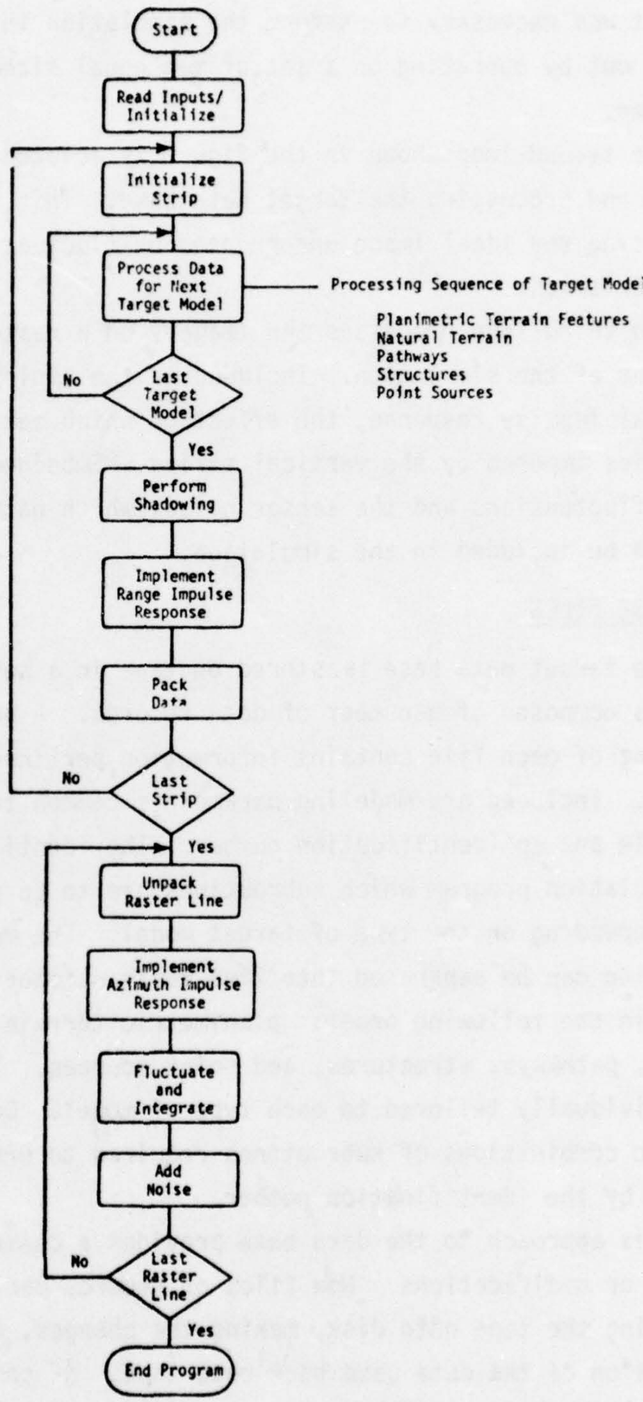

Figure 24. SAR Imagery Simulation Program Flow Chart

used, it was necessary to perform the simulation in pieces. This was carried out by operating on a set of ten equal sized vertical strips, one at a time.

The second loop shown in the figure is devoted to sequentially reading and processing the target data base. This step may be thought of as creating the ideal image uncorrupted by fluctuations and the sensor characteristics.

The third loop processes the imagery on a raster line bases as the last part of the simulation. Included is the implementation of the azimuthal impulse response, the effect of which cuts across the artificial boundaries imposed by the vertical strips. Embedded in this loop are the target fluctuations and the sensor noise, which naturally are the last items to be included in the simulation.

DATA BASE FILES

The target data base is stored on tape in a set of files each of which is composed of a number of data records. A header record at the beginning of each file contains information pertinent to the succeeding records. Included are modeling parameters common to all of the records in that file and an identification number. The identification number informs the simulation program which subroutines are to be used in processing the data, depending on the type of target model. The models used in the simulation can be separated into five major categories which must be processed in the following order: planimetric terrain features, natural terrain, pathways, structures, and point sources. The data base files are individually tailored to each type of model. Consequently, the specific combinations of subroutines required to process each file is indicated by the identification number.

This approach to the data base provides a convenient way to introduce updates or modifications. New files or records can be added or deleted by reading the tape onto disk, making the changes, and then rewinding the new version of the data base back onto tape. Of course, the program can be expanded by adding new target modeling files in their proper order and

including new processing subroutines as needed. This approach provides maximum flexibility and renders the techniques and software applicable to a more general class of problems.

SIMULATION PROCEDURES

The Target

The first step after initialization is to process the target data base. This begins by processing and introducing the planimetric terrain features into the imagery. Points defining line segments form area boundaries which outline the areas. An intensity value is specified and a height is given.

The terrain follows next. This includes the computation of an elevation for each resolution cell in the image from the contour data base. For those pixels encompressed by a planimetric feature, the elevation is added to the feature. The RCS is also calculated and assigned to each pixel not included in a planimetric feature. Since each new set of features added to the scene is in essence overlayed on top of that which is already present, it is imperative that the planimetric and terrain data precede pathways, structure, and point sources. Otherwise these target features would be covered up and not visible to the radar.

Following the terrain, pathways are put into the imagery. The coordinates, height, and width are specified from the geometrical data base. They are added to the terrain and follow the contour of the ground. The radar cross section is then determined from the existing parameters and conditions.

Structures are inserted after pathways. Buildings are treated first and cylinders follow. Buildings are first located oriented, and assigned a height above the ground. If appropriate, buildings are lined up accurately, parallel to streets so that their specular returns are coincident. Then the radar cross section is computed for each pixel encompassing the building. Cylinders are located in the scene and given a height. The radar cross section is also computed for each pixel from the conditions of the simulation.

Point sources are the last targets to be included in the simulation. They are completely specified by a location and cross section both of which are found in the data base.

THE RADAR

After the scene is created in three dimensions, it is necessary to transform the imagery to two dimensions for display.and to incorporate the sensor characteristics and target fluctuations. Shadowing is performed first, resulting in a two dimensional image with the shadowed areas having a radar cross section of zero and showing no radar return.

Implementation of the range impulse response follows the shadowing. Since both shadowing and range smearing are performed in the range dimension (vertical on the imagery), they are implemented during the processing of the vertical strips.

In order to be more efficient in handling the data and to conserve on storage requirement, the strip is then packed and stored for the next step in the program. The CDC 6400 has 60 bit words. The data are packed in 10 bit bytes with 6 bytes per word.

The azimuth impulse response is implemented on a raster line basis, cutting across the strip boundaries. The next step then is to unpack the data and process a raster line at a time. Three operations are performed in this loop. First, the azimuth smearing is imposed. Second, the target radar returns are fluctuated. Lastly, the noise is added to the imagery.

Once the simulation is completed, the synthetic imagery is stored on tape and then displayed on a CRT and/or plotted on film as previously described.

SIMULATION INPUTS

The most important input parameters to the simulation program are listed below:

$\left.\begin{array}{l}\text{Range}\\ \text{Altitude}\end{array}\right\}$ Depression Angle

Orientation (Aspect)

Range Resolution

Azimuthal Resolution
Number of cells in Range
Number of cells in Azimuth
Number of Vertical Strips
Sidelobe Factor
Integration Factor
Noise Factor

These inputs specify the size of the image, the resolution, depression angle, viewing direction, sidelobe level, integration, and noise. A few other inputs are required, but they are related only to the mechanics of producing the simulated imagery.

V. RESULTS

We were asked to demonstrate the methods and simulation software by synthetically reproducing actual SAR imagery of the Stockbridge and Eglin areas. We were given one print of the Stockbridge area and three of the Eglin area. One print of the Eglin area was to be synthetically reproduced as closely as possible. The other two prints of the Eglin area were provided to show the effect of non-coherent integration: One was with the other, without.

Figure 25 is a print resulting from actual SAR imagery. This print was produced by taking a picture of the print provided during the project and reducing the size. This approach was necessary since we did not have access to the original negative. Taking a picture of a print caused some degradation in the fidelity of the actual imagery because of the added film gamma curve. This point is mentioned because we tried to match the imagery in the original print, and our simulated imagery compares (subjectively) slightly better with it than with the print in Figure 25.

The parameters related to the actual Stockbridge imagery made available to us were approximate resolution and depression angle. The resolution is about 20 to 30 feet and the depression angle around 40°. There is no non-coherent integration, and the noise was not specified but assumed to be negligible.

The simulated SAR imagery of approximately the same area under similar conditions is portrayed in Figure 26. The resolution is 30 feet, the depression angle is 20°, and the orientation is virtually the same. A slight amount of noise was included for completeness.

The location of specific targets and features can easily be identified by referring to the data base plots in Section III. However, a few characteristics should be pointed out. The most impressive is the realistic appearance of the simulated imagery. Many observers have found it difficult at first glance to tell which is real and which is simulated. However, after closer inspection, the difference can be discerned.

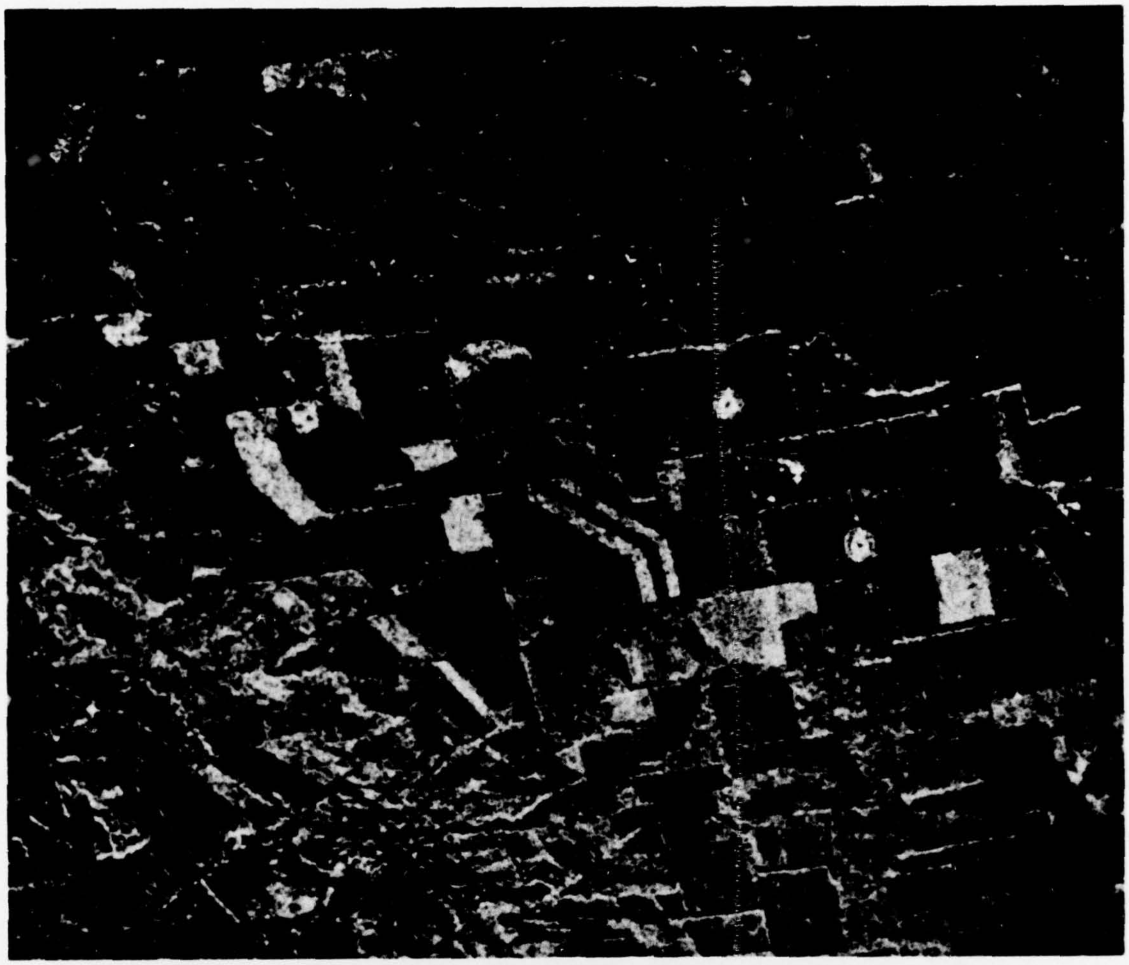

Figure 25. Photograph of Actual SAR Print of Stockbridge
(40° Depression Angle)

Figure 26. Simulated SAR Image of Stockbridge
(20° Depression Angle)

Notice that several of the wooded areas in the simulated imagery almost appear to be reproduced in three dimensions. This effect is also visible in the actual imagery. It results from the leading edge radar return and the shadowing at the far edge, both of which are faithfully simulated. The terrair relief is also evident in the simulated imagery and compares well with the actual imagery. Both the target geometry and the radar cross sections of the simulation compare very well with the actual imagery.

Figure 27 is a simulation with all of the same parameters except that the orientation has been changed by 90°. Thus, the leading edges and shadows are reoriented accordingly. However, the other features remain very nearly the same. (The texture difference is due to the film, not the simulation.)

Figure 28 has the same orientation as Figure 26. Two differences are apparent. The first is that the depression angle has been dropped from 20° to 10°. More shadowing is evident. Secondly, non-coherent integration has been implemented by averaging four adjacent pixels whose corners meet. The effect is both smoothing and a loss of resolution, as can be easily seen by comparing with Figure 26. Although non-coherently integrated imagery was not available for Stockbridge, it was available for Eglin. Two images for comparison are shown in Figures 29 and 30, where Figure 30 is the one resulting from non-coherent integration. A compression of the simulated versions of Stockbridge with these actual images of Eglin demonstrates the fidelity produced in simulating the non-coherent integration.

The actual SAR imagery of the Eglin area that we tried to reproduce synthetically is shown in Figure 31. It corresponds most closely to the photograph used as the basic source data. The simulated imagery is in Figure 32. The parameters of the simulation are the same as those of Figure 26 and the gross characteristics are similar. Notice, however, that the roads in the simulation are much wider than in the real imagery. This results because the roads are wide in the photograph from which the geometric data base was digitized.

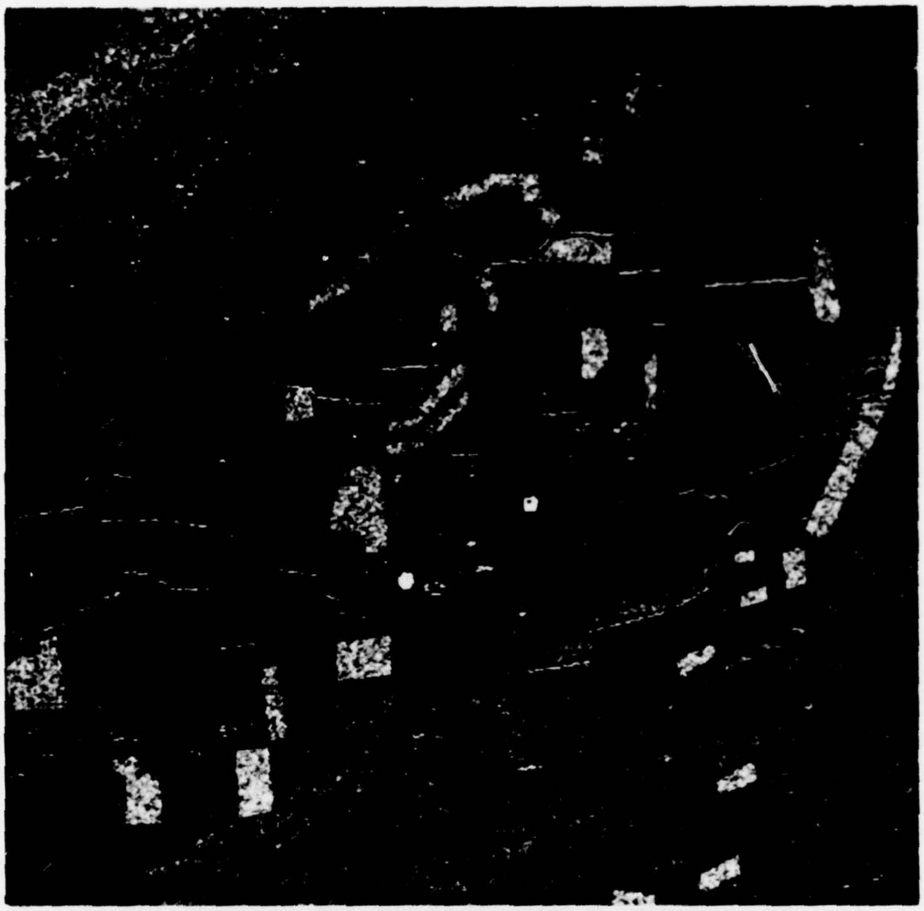

Figure 27. Simulated SAR Image (Rotated 90° in Aspect) of Stockbridge. (20° Depression Angle)

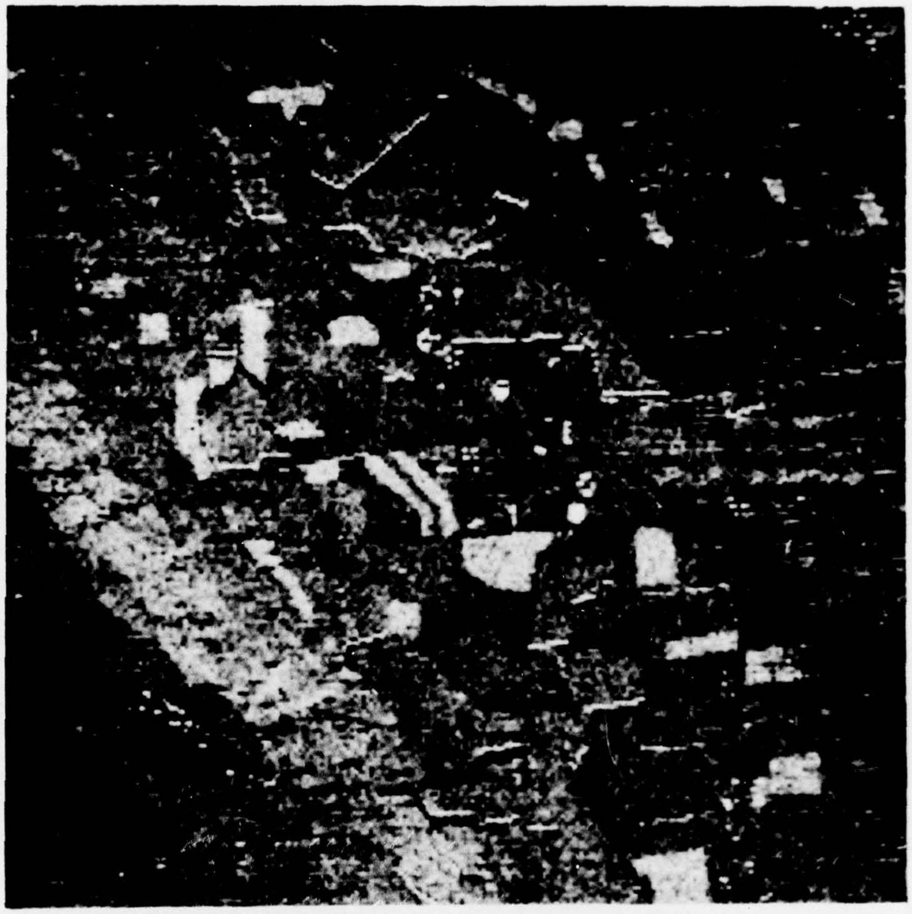

Figure 28. Simulated SAR Image (With Non-Coherent Integration) of Stockbridge. (10° Depression Angle)

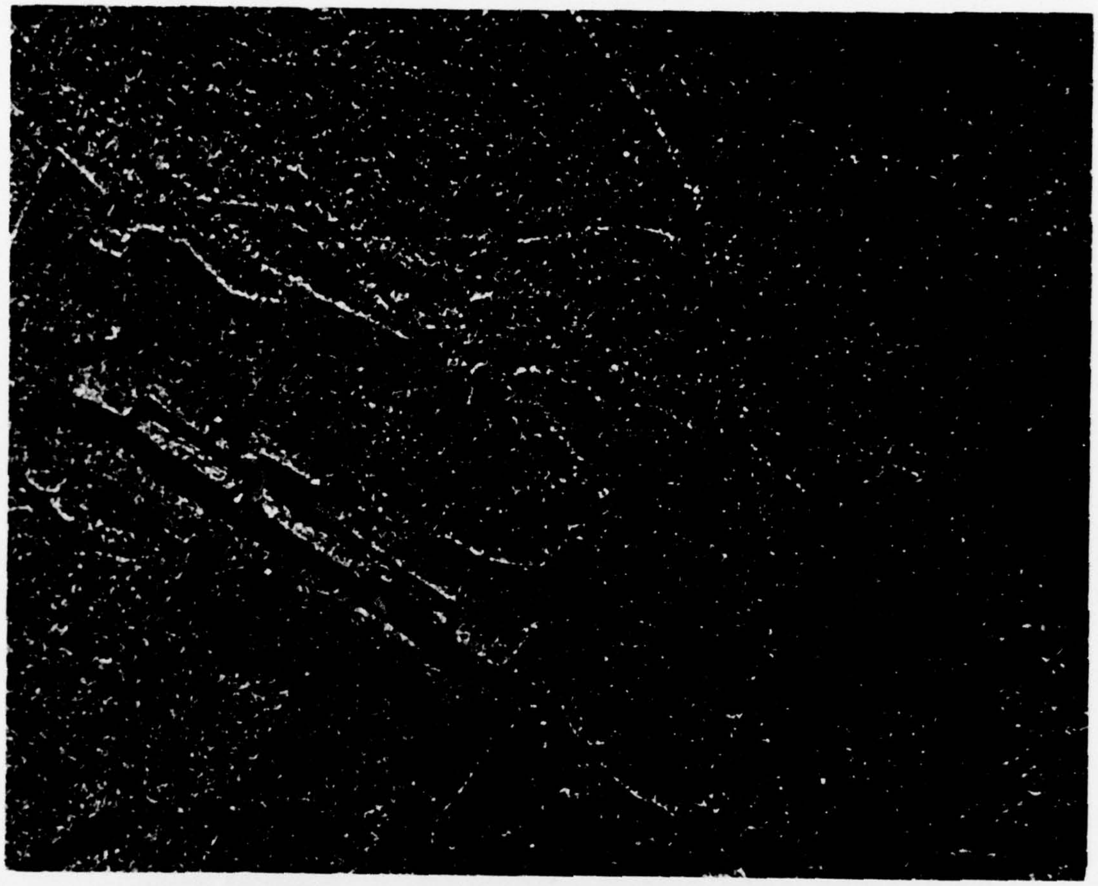

Figure 29. Photograph of Actual SAR Print (Without Non-Coherent Integration) of Eglin Target Area

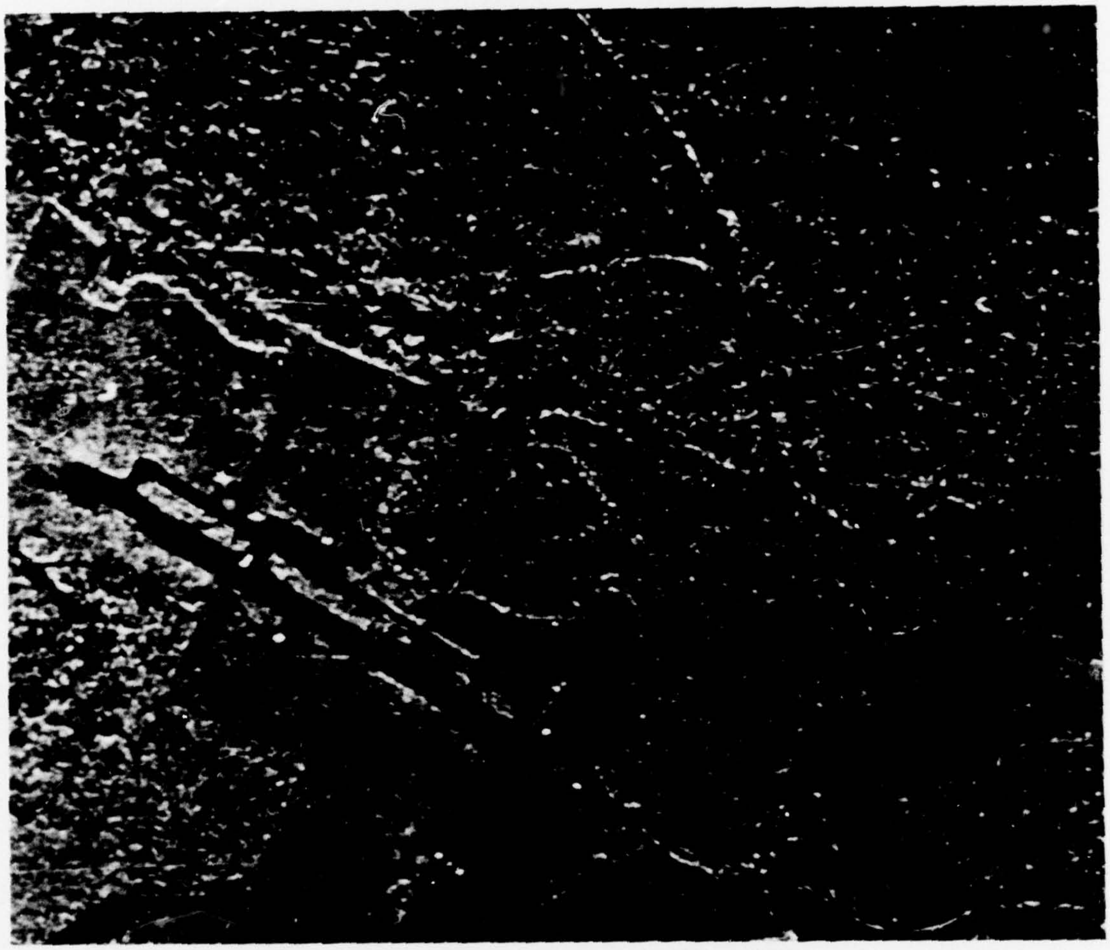

Figure 30. Photograph of Actual SAR Print (With Non-Coherent Integration) of Eglin Target Area

Figure 31. Photograph of Actual SAR Print of Eglin Target Area Corresponding to Simulated Imagery

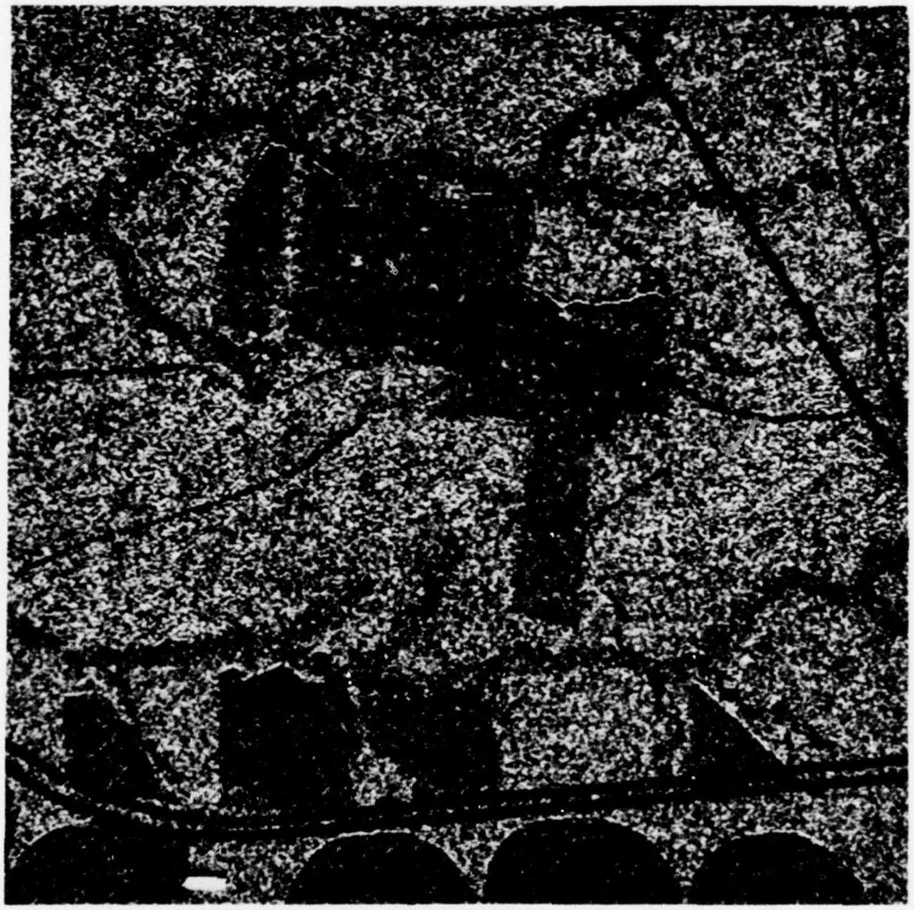

Figure 32. Simulated Imagery of Eglin Target Area

No contour data were implemented in the Eglin simulation because the area is so flat it did not make sense to do so. The realism suffers slightly because of this. If the effective contour data, including the tree and shrubbery heights and variations, had been available, a far more realistic image would have resulted. As it was, this information was impossible to obtain and could not be included. However, we did randomly vary the elevation (artificially roughen the terrain) in certain areas to try improving the realism. The effects were positive but far from a dramatic improvement. These areas were delineated as planimetric features and are plotted as part of the Eglin data base in Section III.

VI. CONCLUSIONS

The major conclusion drawn from this study is that very realistic synthetically generated SAR imagery can indeed be produced for use in exercising change detection processors. A set of powerful techniques and a flexible simulation software package were developed for generating the synthetic SAR imagery. The effectiveness of the program was demonstrated by simulating imagery and comparing it with actual SAR imagery.

It is clearly evident from this simulation that the output imagery is far better when the input data are more detailed. For example, the (effective) terrain relief data were available of Stockbridge, but not for Eglin, and the resulting imagery shows the difference. This implies that the simulation techniques and software reported in this study will produce better imagery with improved fidelity and realism if greater attention is paid to the data base.

REFERENCES

1. Mitchell, R. L., A. B. Lucero, R. E. Harrison, and D. J. Arnold, "Synthesis of High-Resolution Radar Systems for Display Simulation and Training," AFHRL-TR-71-11, Air Force Human Resources Laboratory, Wright-Patterson AFB, Ohio, June 1971.

2. Mitchell, R. L., A. B. Lucero, and R. E. Harrison, "Simulation of High-Resolution Radar Displays of City Complexes," AFHRL-TR-73-11, Air Force Human Resources Laboratory, Wright-Patterson AFB, Ohio, August 1973.

3. Ball, Margaret, "Digital Simulation of High Resolution Side-Looking Radar Imagery: Computer Software Documentation," TSC-PD-B486-1, Technology Service Corporation, Santa Monica, California, May 1976.